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(UNCLASSIFIED TITLE)

MONTHLY PROGRESS REPORT NO. 17
DEVELOPMENT OF A SUPERSONIC TRANSPORT AIRCRAFT ENGINE
PHASE II-C

1 NOVEMBER THROUGH 30 NOVEMBER 1966

CONTRACT NO. FA-SS-66-8

(Competitive Data)

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SECTION I
SUMMARY OF PROGRESS

- Testing of the prototype configuration high compressor in the high compressor rig has resulted in performance which either meets or exceeds the airflow, efficiency, and pressure ratio requirements for the JTF17A-21 production rating. This configuration is being assembled into engine FX-163 and is scheduled for sea level maximum thrust calibration testing early in December.

- Engine FX-161 has completed a program at simulated cruise conditions with inlet distortion representative of the maximum level for the intended installations. The engine did not encounter stall or surge and no measurable effect on engine performance was noted. Engine disassembly to date has shown no parts discrepancies and the engine is scheduled to be reassembled for sea level testing in December.

- Testing of the 0.6-scale fan rig with inlet distortion in excess of both Boeing and Lockheed cruise distortion has shown no effect on the engine-side surge line and only a 3% loss in surge margin on the duct side. The gas generator and duct sides attenuated the distortion more than predicted. This rig has been reassembled with redesigned 1st and 2nd-stage blades and is scheduled for testing early in December.

The Source Selection Council visited FRDC on 10 November for JTF17 engine discussions. The FAA Supplementary Engine Evaluation Task Force visited FRDC on 16 and 17 November to review the SST engine and rig test results since the SST evaluation team visit the week of 19 September. Numerous meetings were held with Boeing and Lockheed personnel in a continuing effort to keep engine/airframe coordination current.

The following significant achievements have been made on the JTF17A-20 experimental engines:

Total engine time	137.89 hours
Total duct heating time	26.20 hours*
Time at 2000°F and above	52.15 hours
Time at 2200°F and above at cruise (M 2.7, 65,000 ft)	14.27 hours
Heated inlet time	32.34 hours
Time at cruise conditions (Mach 2.7, 65,000 ft)	28.59 hours

*This time was erroneously reported as 35.00 hours in the summary of last month's report.

SECTION II
PROBLEM REPORT

Engine FX-161-5 completed 7.52 hours of testing in the altitude test stand, and subsequent disassembly has shown no further problem in the areas found after build No. 4 reported in last month's report (PWA FR-2156). Revisions incorporated and tested during this build of engine FX-161 were as follows:

1. Harder insert bushing at the duct heater support bosses and wear-resistant coating on the support pins
2. Inner duct heater quarter panel supports with heavier tie strips and rivets replacing spot welds
3. Addition of sharp leading edge extensions to the main diffuser case struts to reduce individual peak temperatures
4. Reoperation of the aft end of the film-cooled transition duct to provide additional cooling air over the turbine vane ID platform
5. Reoperation of the 1st-stage turbine vane cooling air tube ID by installing a bleed slot to purge the vane ID platform support cavity.

A revision to seal the riveted rear flange of the No. 1 seal support was incorporated in engine FX-161-5. This change eliminated the coking problem experienced on engine FX-161-4, resulting from leakage past the rivets into the labyrinth seal pressure supply area of the intermediate case. Disassembly of the engine after 7.52 hours of running indicated no leaks at this flange. This revision has been incorporated in both No. 1 and No. 2 seal supports on engine FX-163-2.

Tablocks to replace indented lockwashers for the duct heater Zone II fuel nozzle covers will be evaluated on the next build of engine FX-161.

SECTION III
DESCRIPTION OF TECHNICAL PROGRESS

A. ENGINE DESIGN

1. Fan

Layouts of a new 0.6-scale fan rig for Phase III were completed.

2. Compressor

The prototype compressor design layouts were completed. This compressor has the same aerodynamic design as the compressor rig that demonstrated performance capability above specification requirements in early November.

Design layout work continues to define the incorporation of this prototype compressor into a third compressor rig for use during Phase III development.

3. Primary Combustor

The design of the primary combustor is 90% complete. The design concept is the same as described in the Phase III proposal.

A convectively cooled transition duct design has been completed and an alternative film-cooled transition duct design has been initiated.

The engine diffuser case design is also 90% complete.

4. Duct Heater

Design layouts of the combuster, duct heater support case, and rear mount case are complete.

Design is continuing on the duct diffuser case, inner and outer liners, and Zones I and II fuel injection systems.

5. Turbine

An alternative 1st-stage blade illustrated in figure III-A-1 has been designed.

The design of the turbine high spool rig for Phase III is continuing.

6. Shafts, Bearings, and Seals

The design layouts for the No. 1 and 2 bearing compartments are complete. The No. 3 compartment design is approximately 90% complete. The No. 4 compartment is approximately 70% complete.

7. Accessory Drives

Design layouts of the Boeing power takeoff hydraulic pump drive gearbox and of the Lockheed engine-driven compressor gearbox were completed. Design layout work for the engine accessory gearbox continues. This gearbox housing design is being coordinated with the engine hydraulic and fuel pumps and the quick-disconnect feature for the engine unitized fuel control.

Accessory and starting drive bevel gear sets located within the No. 1 and 2 bearing compartments have been completely designed.

8. Fuel System

The design layout for plumbing through the struts, utilizing strut covers with integral fittings, was completed during this report period.

Revised plumbing layouts were provided in this period for the experimental engine gas generator to accommodate the incorporation of the prototype compressor in the experimental engine.

9. Control System

Coordination with vendors on the unitized fuel control, main fuel pump, and hydraulic pump was continued. A mockup of the revised connection between the fuel control base plate and the accessory drive gearbox was constructed to evaluate the accessibility of the connection for easier gearbox replacement. A preliminary layout of the unitized fuel control-gearbox mounting system, and a stress analysis of this system were completed in this period.

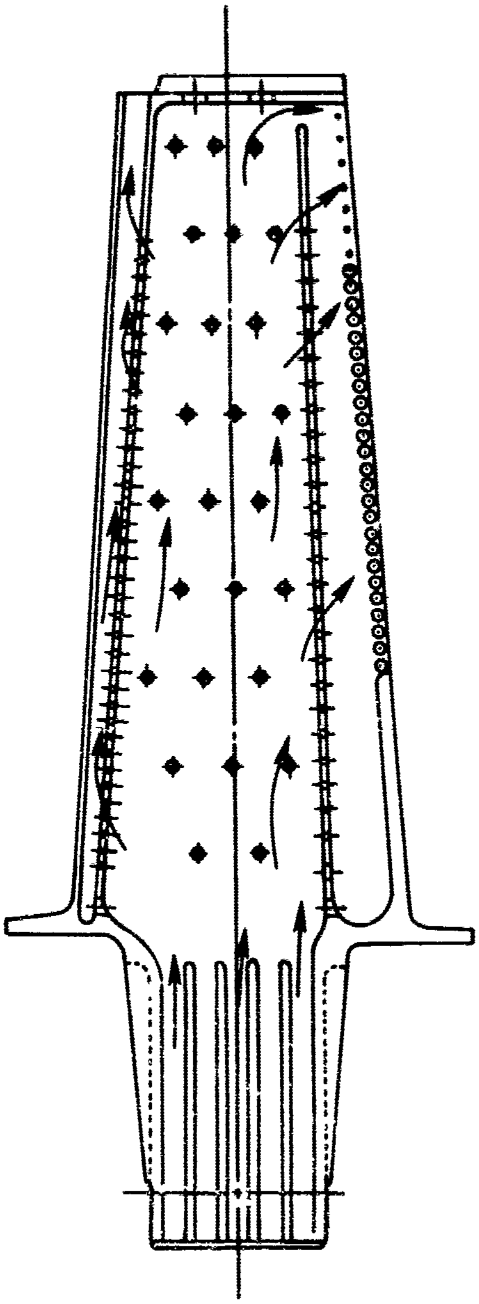
The design layouts of the combined drain valves and the fuel-oil cooler were completed in this period. Design work on the aerodynamic brake actuator and the duct nozzle feedback system was continued. Design of the reverser interlock mechanism and the coupling to the unitized fuel control is progressing.

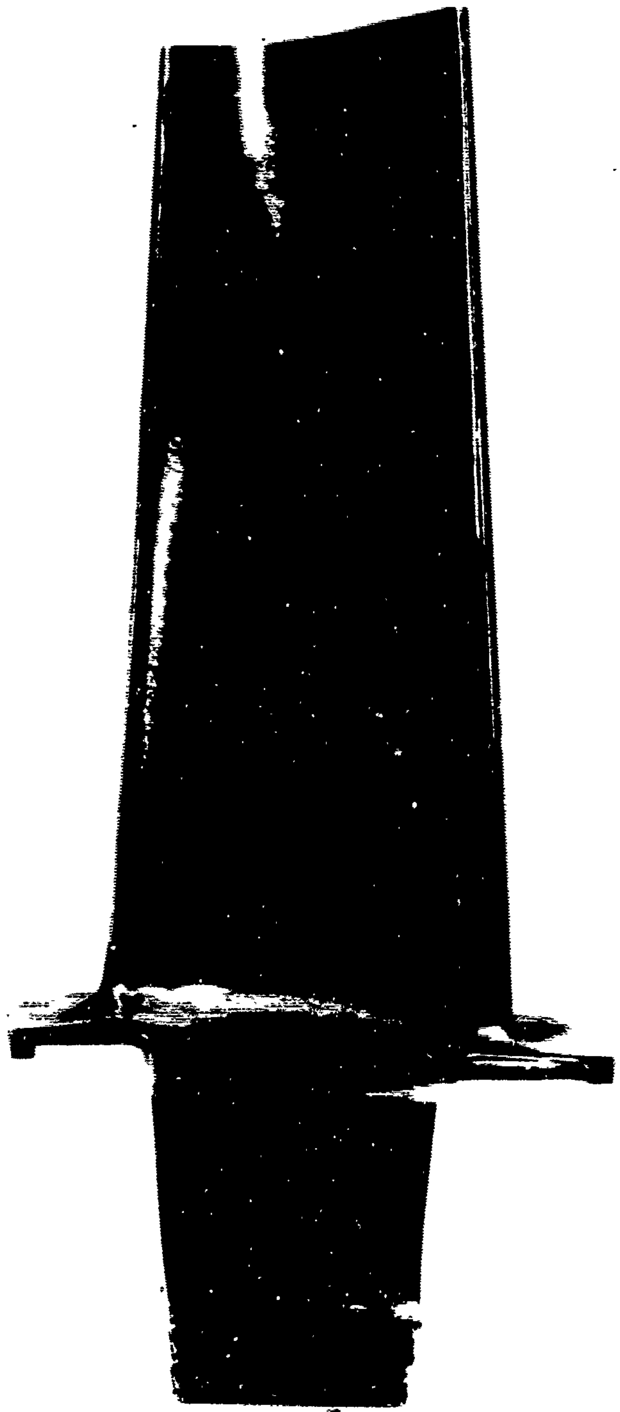
10. Lubrication System

The design layout of the secondary (oil pump-cabin air compre -
drive gearbox for the JTF17A-21L engine was completed in this period.

11. Reverser-Suppressor

The design layouts of the JTF17A-21 reverser-suppressor and duct heater variable nozzle are continuing.





J58 Blade with
Same Cooling Scheme

Figure III-A-1. Alternate 1st-Stage Turbine Blade Cooling Scheme FD 17094

B. ENGINE TEST

	November Time, hours			Phase II-C Time, hours			
Engine	FX-161	FX-162	FX-163	FX-161	FX-162	FX-163	Total
Total	7.52	No Testing in the November Report Period	No Testing in the November Report Period	87.41	47.55	2.93	137.89
Heated Inlet	7.52			30.27	2.07	0	32.34
Cruise Condition (M = 2.7 at 65,000 ft)	5.90			26.94	1.65	0	28.59
Duct Heater							
Total	1.20			20.43	5.77	0	26.20
Cruise Condition (M = 2.7 at 65,000 ft)	1.20			6.17	0	0	6.17
Turbine Inlet Temperature							
2000°F and above	4.48			35.71	15.84	0.60	52.15
2100°F and above	4.00			26.40	15.64	0.37	42.41
2200°F and above	3.68			18.41	5.85	0.12	24.38
2200°F and above at cruise conditions (M 2.7, 65,000 ft)	3.68			14.27	0	0	14.27
2300°F and above	0			0.59	0.38	0	0.97

Testing of the prototype configuration high compressor in the high compressor full-scale rig has resulted in performance that either meets or exceeds the airflow, efficiency, and pressure ratio requirements for the JTF17A-21 production rating. The excellent performance of the prototype compressor is illustrated by the data presented in figure III-B-1. Figure III-B-2 illustrates the improved surge characteristics relative to the current Phase II-C high compressor requirements and builds No. 3 and No. 5 of the JTF17A-20 compressor. This configuration is being assembled into engine FX-163 and is scheduled for sea level maximum thrust calibration testing early in December.

Engine FX-161 has completed a program at simulated cruise conditions with inlet distortion representative of the maximum leve, for the intended installations. The inlet distortion was simulated by mounting a gradated density screen, figure III-B-3, eight feet ahead of the engine. The overall inlet distortion, (Max P_{T2} - Min P_{T2})/Average P_{T2}, was 8.9% with K_{d2} = 374, as shown in figure III-B-4. The engine did not encounter stall or surge and no measurable effect on engine performance was noted. Engine disassembly to date has shown no parts discrepancies and the engine is scheduled to be reassembled for sea level testing in December.

Testing of the 0.6-scale fan rig with inlet distortion in excess of both Boeing and Lockheed cruise distortion has shown no effect on the engine-side surge line and only a 3% loss in surge margin on the duct side. See figure III-B-5. The gas generator and duct sides attenuated the distortion more than predicted. A schematic of the test configuration is shown in figure III-B-6, and the distortion screen used is shown in figure III-B-7. This rig has been reassembled with redesigned 1st- and 2nd-stage blades and is scheduled for testing early in December.

1. Engine FX-161

a. Rebuild

The fifth build of the engine was completed and it was delivered to the altitude test facility on 14 November for evaluation of inlet effects and altitude performance. The following is a summary of features included in this build:

FAN - Same as build No. 5 configuration; strain gage instrumentation on both stages.

INTERMEDIATE CASE - Drooped fan discharge splitter as part of the build No. 5 fan; pressure instrumentation added to strut leading edges on main engine side.

HIGH COMPRESSOR - Same as build No. 5 configuration.

MAIN DIFFUSER - Sharp leading edge extensions on struts; instrumentation bosses for compressor discharge traverses; heavyweight splitter from previous builds.

PRIMARY COMBUSTOR - Original primary combustor with film-cooled transition duct with the trailing edge of the inner duct modified to provide additional cooling air for the ID platform of the 1st-stage turbine vanes.

TURBINE - Additional cooling airflow to the 1st-stage turbine vane ID platform support cavity as used on engine FX-163-1. The damper weights were reoperated to assure uniform loading of the damper weight on the 1st-stage turbine blade platforms. The round hole in the damper weights was changed to a triangular shape hole to reduce frictional contact area. The width of the yokes, which retained the damper weights, was also decreased to reduce the possibility of binding on the tips of the adjacent dampers. (See figure III-B-8.)

TURBINE EXHAUST SECTION - Primary nozzle resized for speed matching with the build No. 5 fan.

FAN DIFFUSER - Modified to accommodate the compressor discharge traverse probes.

DUCT HEATER - Hard sleeves of L-605 material installed in the support pin holes and tungsten carbide hard faced pins; octagonal nozzle from previous builds.

COMPONENTS - Manual control of main engine fuel flow, duct heater fuel flow, duct heater nozzle, and vane angles.

GEARBOXES - Same as build No. 4.

b. Test Program

The engine was installed in the altitude test stand with an inlet distortion screen to simulate the Boeing distortion pattern. The screen and the duct for fan strain gage instrumentation are shown in reference figure III-B-3. Two runs were made for evaluation of airflow patterns. The distortion screen was rotated between the runs to effectively double the instrumentation. The overall inlet distortion, (Max P_{T2} - Min P_{T2})/Average P_{T2}, was 8.9% with K_{d2} = 374, reference figure III-B-4. The inlet distortion screen was removed and a baseline calibration was run without distortion. For further evaluation of the data, see paragraph 3-B, Performance. Fan blade strain gage readings were less than 10,000 psi for all testing.

The altitude program included testing at cruise conditions with heated fuel and lubricant. A fuel temperature of 360°F was measured at the inlet to the nozzle support. This would result in a maximum fuel temperature of 370°F at the fuel nozzle. Refer to section III-D for additional information on the fuel nozzles after test and section III-J for the fuel quality. During the engine testing at cruise conditions, a maximum lubricant temperature of 360°F out of the No. 4 compartment was measured.

The engine was removed from the altitude test stand and delivered to the assembly floor for inspection and to incorporate changes for a sea level performance program.

c. Disassembly Inspection

The engine has been disassembled and inspection of all parts is in progress. No obvious parts discrepancies were seen during disassembly.

2. Engine FX-163

Engine disassembly was completed on 19 October. All parts were inspected and reviewed in preparation for rebuild. Reference October Progress Report No. 16, PWA FR-2156. Assembly was initiated, replacing damaged parts only, but this plan was revised to incorporate the high pressure compressor to the configuration that demonstrated performance capability above specification requirements in the compressor rig. (See paragraph C, Compressor.)

A general description of the major features being incorporated in engine FX-163-2 follows:

FAN - Same as rig build No. 5 configuration with a new, increased strength outer fan shroud. The increased strength outer shroud, figure III-B-9, eliminates the need for dampening bands required on the original design as shown in figure III-B-10.

INTERMEDIATE CASE - Same as on engine FX-163-1 which included the drooped splitter as part of the prototype fan package.

HIGH COMPRESSOR - Same as prototype configuration featuring increased chord length vanes and blades incorporating new vane and case assemblies, new inlet guide vanes, steel blades from

the compressor rig, (AMS 5616 Greek Ascoloy), No. 3 through 6 disks from the compressor rig, and No. 7 and 8 disks from engine FX-163-1.

This configuration is three inches longer in overall length because of the increased chord length of the vanes and blades and includes a 5th-stage starter bleed system.

The inlet guide vanes are variable and the 3rd- and 7th-stage vanes are fixed. See section III-C for a detailed description.

MAIN DIFFUSER - No changes from engine FX-163-1 that had sharp LE extensions on the diffuser struts. For this build, four starter bleed valves were mounted on the diffuer outer wall to provide supplemental bleed air capacity for starting only.

PRIMARY COMBUSTOR - Same as engine FX-163-1 which included heavyweight splitter, standard combustor unit, and film-cooled transition ducts. The outer transition duct is two-piece, and the inner transition duct provides a flow of cooling air over the ID platform of the 1st-stage turbine vanes.

TURBINE - Same configuration as on engine FX-163-1. First-stage blades are of the nongated airfoil type from engine FX-161-5.

TURBINE EXHAUST SECTION - The OD wall contour on the exhaust case is revised to reduce the back pressure on the turbine, and the exhaust nozzle contour is revised to reduce base area drag losses. See figure III-B-11.

FAN DIFFUSER SECTION - Same as engine FX-163-1, original configuration.

DUCT HEATER - Same as engine FX-163-1, original combustor section with round, balanced flap variable nozzle.

COMPONENTS - Same as engine FX-163-1 which included the automatic duct heater control.

GEARBOXES - Same as engine FX-163-1.

PLUMBING - Same as engine FX-163-1 except for changes necessary to accommodate the prototype compressor, the starter bleed system, and the revised turbine exhaust case.

REVERSER-SUPPRESSOR - Unit No. 2, identical to unit No. 1, will be installed at test after completion of the initial performance test program.

Completion of engine assembly and delivery to A-4 sea level test stand is scheduled for early December. The primary objective of this test is to demonstrate increased sea level static engine performance.

3. Performance

During November, engine FX-161-5 was tested at supersonic cruise conditions with and without simulated inlet distortion to demonstrate engine-inlet compatibility. The inlet distortion was simulated by mounting a gradated density screen, reference figure III-B-3, eight feet ahead of the engine. The pressure distortion generated by this screen, (Max P_{T2} - Min P_{T2})/Average P_{T2} was 8.9% with a distortion factor, K_{d2}, of 374. The differences in measured engine parameters, with and without distortion, are compared in table III-B-1 and show no effect on performance resulting from the distortion screen. The turbine inlet temperature radial profile with distortion was unchanged from the profile without distortion as shown in figure III-B-12. Peak 1st-stage turbine vane temperature with distortion was within 15° of the peak temperature without distortion.

Table III-B-1. Effect of Distortion
Mach 2.7, 65,000 ft

Parameter	Change Due to Distortion
$N_1/\sqrt{\theta_{T2}}$	+ 0.05%
$N_2/\sqrt{\theta_{T3}}$	+ 0.4%
P_{T4}/P_{T2}	+ 1.0%
$(P_{T4} - P_{T5})/P_{T4}$	No change
T_{T5}	- 12°F
P_{T7}/P_{T2}	+ 1.2%
$W\sqrt{\theta_{T2}}/\delta_{T2}$	+ 0.1%

4. Materials and Fabrication

Long-time stress rupture and creep rupture testing is nearing completion on candidate SST materials. Stress rupture testing has been completed on Hastelloy X Sheet (AMS 5536). This curve was submitted in prior reports and will not be repeated in this or subsequent reports.

A list of candidate materials, the proposed applications in the SST design, and the limiting creep and stress design criteria are tabulated as follows:

Material	Application	Limiting Creep, %	Design Criteria Creep and Stress Rupture Temp Range, °F	High Time Specimen, hr
Astroloy (PWA 1013)	Disks	0.1	1200-1400	4745
Waspaloy Sheet (PWA 1030)	Cases	0.5	1200-1600	5113
Waspaloy Forgings (PWA 1016)	Disks, Shafts, Hubs	0.1	1100-1300	3587
Inco 718 Sheet (PWA 1033)	Ducts, Cases	0.5	1000-1200	3220
L-605 Sheet (AMS 5537)	Ducts, Liners	0.5	1400-1800	5203
Hastelloy X Sheet (AMS 5536)	Burners, Ducts	0.5	1400-1800	4761
IN-100 (PWA 658)	Blades, Vanes	1.0	1400-1800	4950
Inco 625	Duct, Liners		1200-1500	998
TD Nickel (PWA 1035)	Vanes		1700-2100	2023
Titanium (PWA 1202)	Blades	0.1	700-900	7541
PWA 664	Blades	1.0	1400-1800	3060
A-110 (AMS 4910)	Cases	0.1	700-900	[illegible]52

The results of long-time stress rupture and creep testing of the following current alloys are plotted in figures III-B-13 through III-B-18.

Material	Stress Rupture Figure No.	Creep Figure No.
Astroloy (PWA 1013)	*	*
Waspaloy Sheet (PWA 1030)	III-B-13	III-B-14
Waspaloy Forgings (PWA 1016)	*	*
I-718 Sheet (PWA 1033)	*	*
L-605 Sheet (AMS 5537)	*	*
Hastelloy X Sheet (AMS 5536)	*	*
IN-100 (PWA 658)	III-B-15	*
Inco 625	*	*
TD Nickel (PWA 1035)	III-B-16	III-B-17
PWA 664	III-B-18	*
Titanium (PWA 1202)	*	*

*Testing completed. Curves in previous reports.

5. Sulfidation and Oxidation - Erosion Testing

Sulfidation testing is being continued on the most promising candidate SST materials and coatings. The following is a summary of sulfidation testing conducted at accelerated test conditions of 1.0 ppm NaCl content in air, maximum sulfur content allowed (0.3%) by PWA fuel specifications 522 and specimen metal temperature of 1800°F.

Material	Coating	Protection, hr
PWA 1035 (TD Nickel)	PWA 62	1250
PWA 664	PWA 47	1350
PWA 664	PWA 64	1850
PWA 658 (IN-100)	PWA 64	1150
PWA 658 (IN-100)	*	2500
PWA 1035 (TD Nickel)	*	1100**

*PWA number has not been assigned
**Testing of specimens still in process.

A graphic representation of these data is shown in figure III-B-19. The sulfidation testing and retesting results presently in process on the following materials and coatings are: (1) PWA 1035 (TD Nickel) coated with the newly developed coating showed excellent sulfidation protection after 1100 hours of total testing, (2) PWA 658 (IN-100) coated with the newly developed coating showed excellent sulfidation protection after 1100 hours of total testing, (3) PWA 658 (IN-100) and PWA 664 coated with PWA 64 showed excellent sulfidation protection after 550 hours of retesting. The conditions of these specimens are shown in figure III-B-20.

Long-time oxidation-erosion testing of candidate SST materials and coatings (also other materials and coatings for comparison) is continuing at 1800°F specimen metal temperature. The results for the following material and coatings being tested are: (1) PWA 658 (IN-100) coated with PWA 58, and PWA 664 coated with PWA 47 showed excellent oxidation-erosion protection after 1300 hours of testing; (2) PWA 657 (SM-302) coated with PWA 45 showed excellent protection after 500 hours of testing; (3) PWA 1035 (TD Nickel) coated with PWA 62 showed excellent protection after 350 hours of testing; (4) PWA 664 and PWA 658 coated with PWA 64 showed excellent protection after 450 hours of testing. The conditions of these specimens after the testing time indicated are shown in figure III-B-21. Graphic presentation of these data are shown in figure III-B-22.

6. Advanced Material Development (Related Technology)

a. Ni-Mo-Al (Advanced Cast Turbine Vane Alloy)

The Ni-Mo-Al composition has been officially designated NX 188. First-stage J58 turbine vanes are being cast for engine evaluation. A chromize coating for NX 188 is undergoing sulfidation-erosion testing at 1800°F. Coated test bars look excellent after 500 hours of rig testing.

b. Astroloy Sheet Program

In addition to the production quantity of Allvac sheet, which is being evaluated, a similar quantity of Eastern stainless sheet is being evaluated. The weld studies, outlined in last month's progress report, are continuing. A second afterburner duct will be fabricated from the Eastern stainless material.

c. UX-1500 (Turbine Disk Alloy)

The UX-1500 ingot has been given a second homogenization cycle to clean up an undesirable segregate found in the subscale forgings. This phase or segregate could not be removed through heat treatment and negated the obtaining of optimum mechanical properties. Additional subscale forgings are to be made prior to forging a full-size disk.

d. Extrusion Forgings of IN-100 and Modified Mar M-200 Alloys (Turbine Blade Application)

Evaluation of the effect of prior work on the mechanical properties of wrought IN-100 is being made. Further work is being performed to analyze grain boundary condition and the effect on ductility.

e. Advanced Titanium

Testing is continuing on forged pancake specimens of Ti 6-2-4-2, Ti 6-2-4-2 + 1.5 Si, IMI 679 (PWA 1205), and Hylite 60 for comparison with PWA 1202 properties.

7. Engine Accessories

a. Compressor Bleed Valves

The JTF17A-20 compressor bleed valves are air actuated, spring loaded poppet valves that bleed compressor discharge air to the cavity surrounding the gas generator. These valves were used during engine testing to vary the percent of bleed airflow during starting and operation of the engines. Operation of the valves during sea level and altitude running of the engines was flawless.

Calibration and environmental bench tests were performed. The component calibration test consisted of measurements for actuation pressure, piston ring leakage, and valve seat leakage. The environmental test consisted of cycling the valve for 5000 cycles in a 1050°F environment. Two valves were subjected to the environmental test. Pre- and post-test calibration data of the valves were in good agreement, and within the limits of the component calibration schedule as illustrated in table III-B-2. The detail parts of each valve were in excellent condition.

The total test time accumulated is as follows:

Engine	-	218.19 hours
Calibration	-	28.33 hours
Environmental	-	87.32 hours
Total	-	333.84 hours

The features of these bleed valves that have demonstrated successful operation during this phase have been employed in the Phase III design of the JTF17 engine valves.

Table III-B-2. Bleed Valves

Parameter	Pretest	Post-Test
Pressure-to-Actuate:		
Open to close	1.5 psi	1.5 psi
Close to open	0.5 psi	0.5 psi
Piston Ring Leakage	0 pph	0 pph
Valve Seat Leakage	0 pph	0 pph

b. Actuators

Linear hydraulic actuators were employed on the JTF17A-20 engine for operation of the high compressor variable vanes, the variable area duct heater exhaust nozzle, and the reverser-suppressor clamshells. These actuators employ engine fuel as the working fluid and incorporate design features that were developed for actuators used on the high performance J58 engine. Operation of the actuators during engine testing at sea level and altitude conditions was very satisfactory.

Calibration and environmental bench tests were performed. The component calibration test consisted of measurements for actuation pressure, cooling flow rate, length of stroke, and dynamic seal leakage

The environmental test was a 75-hour design verification test that was conducted under the following conditions:

1. Ambient temperature - 900°F
2. Fuel inlet temperature - 350°F for 4 hours
   150°F for 1 hour
   - cycle repeated every 5 hours
3. Actuator stroke - 1 in. (nominal full stroke - 4.2 in.)
4. Actuator cycle rate - 90 cycles per minute
5. Open to close pressure - 1500 to 2000 psi
6. Overboard drain leakage - 5 cc/min (max).

Pre- and post-environmental test calibration data were in excellent agreement as illustrated in table III-B-3, and the actuator parts showed little or no distress.

The total test time accumulated is as follows:

Engine	-	1097.14 hours
Calibration	-	89.09 hours
Environmental	-	96.24 hours
Total	-	1282.47 hours

Table III-B-3. Actuators

Parameter	Calibration	
	Pretest	Post-Test
Pressure to Actuate:		
Open to close	60 psi	20 psi*
Close to open	35 psi	10 psi*
Overboard Drain Leakage	0 cc/min	1.5 cc/min
Stroke	4.369 in.	4.352 in.
Cooling Flow Rate	215 pph	216 pph

*Normal range after environmental cycling as determined from J58 experience.

c. Lines and Fittings

The JTF17A-20 lines and fittings that have been used in the Phase II-C engine program are fabricated from stainless steel tubing (AISI type 347) and Inconel materials. The fittings are either brazed and integral tube AN type that use soft nickel conical gaskets or the threaded or bolted flange type that use metal K-seals.

These lines and fittings, which were designed using the criteria and experience from the development of the J58 engine, have provided excellent service during engine and rig operation. Only one tube failure, induced by preload as a result of improper component installation, has occurred during all engine testing.

An investigation using titanium tubing has been conducted with commercially pure tubing, grade A-40, and the alloy tubing, 3Al-2.5V. These materials were successfully upset to the standard integral ferrule

configuration for AISI type 347 material (PWA 770). Vibratory fatigue tests under simulated engine environmental conditions were conducted on the integral ferrule and on the welded tube-connector configurations. In addition, salt water corrosion tests, bend tests, and brazing tests (for brazing tubing standoff supports to the tubing) have been conducted.

From the testing of titanium tubing it is concluded that the tubing alloy 3Al-2.5V is comparable to or better than the AISI type 347 tubing material and will provide a suitable tubing material. Because of low vibratory fatigue strength, the commercially pure titanium tubing is unsatisfactory. The investigation of the titanium alloy is being continued.

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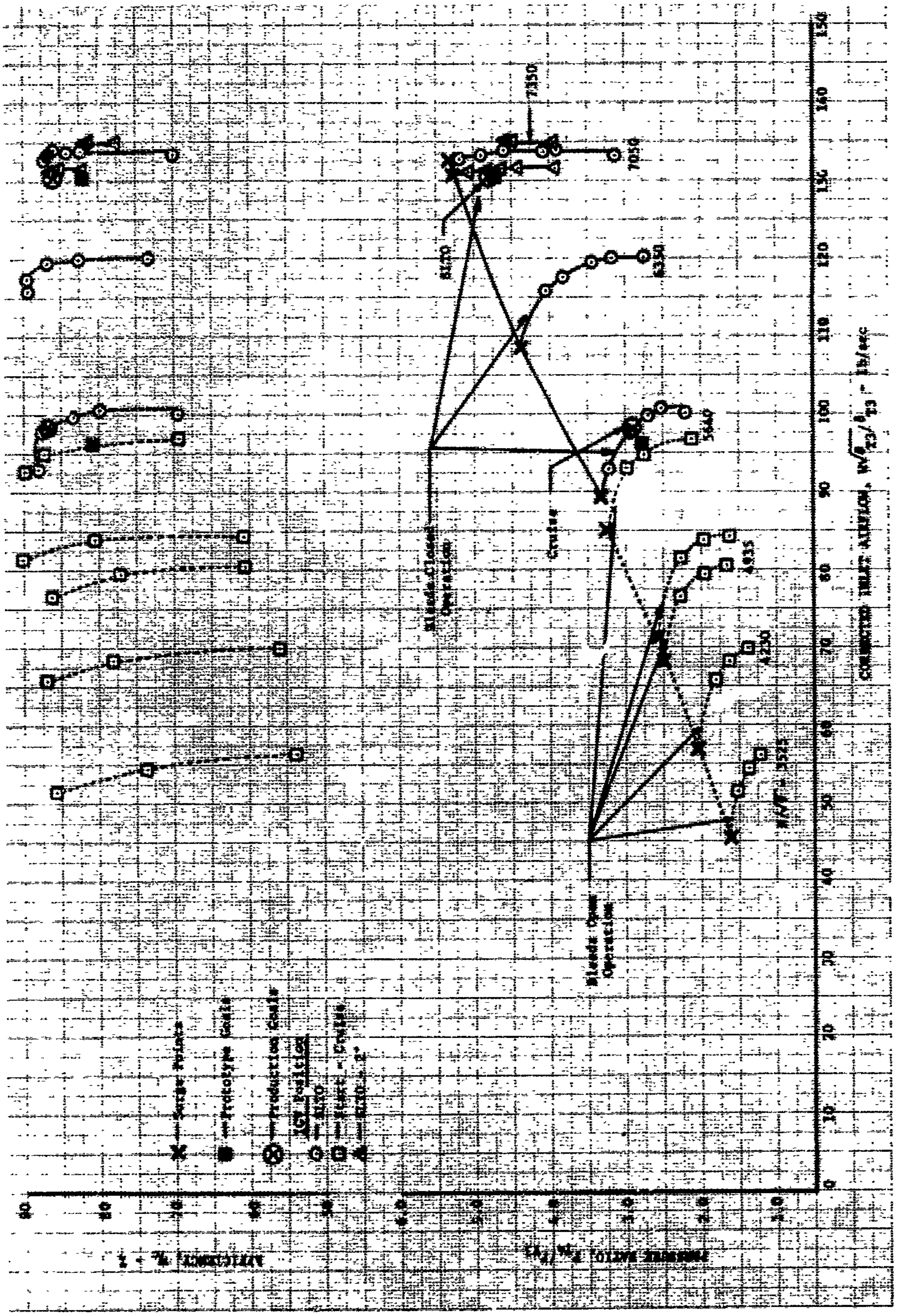

Figure III-B-1. JTF17A-21 Prototype High Pressure Compressor Rig Performance

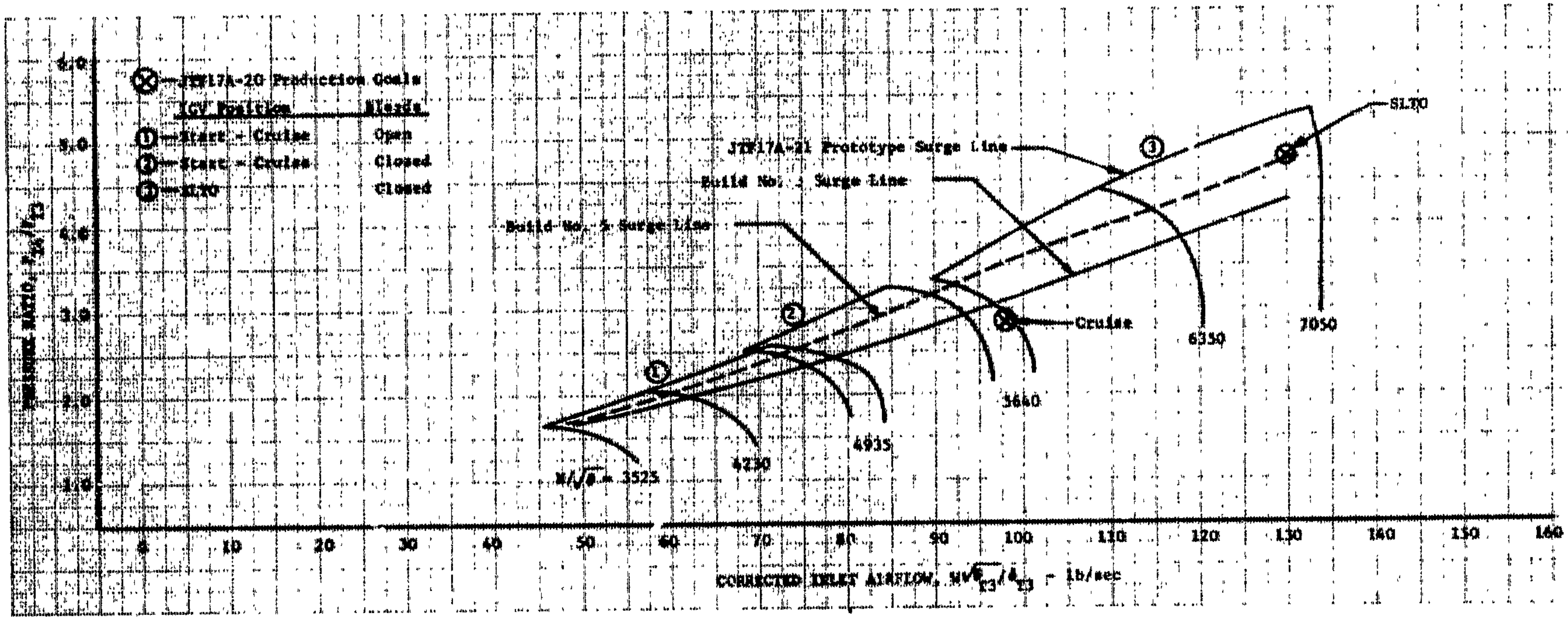

Figure III-B-2. Comparison of JTF17A-21 Prototype and Demonstrator High Pressure Compressor Rig Performance

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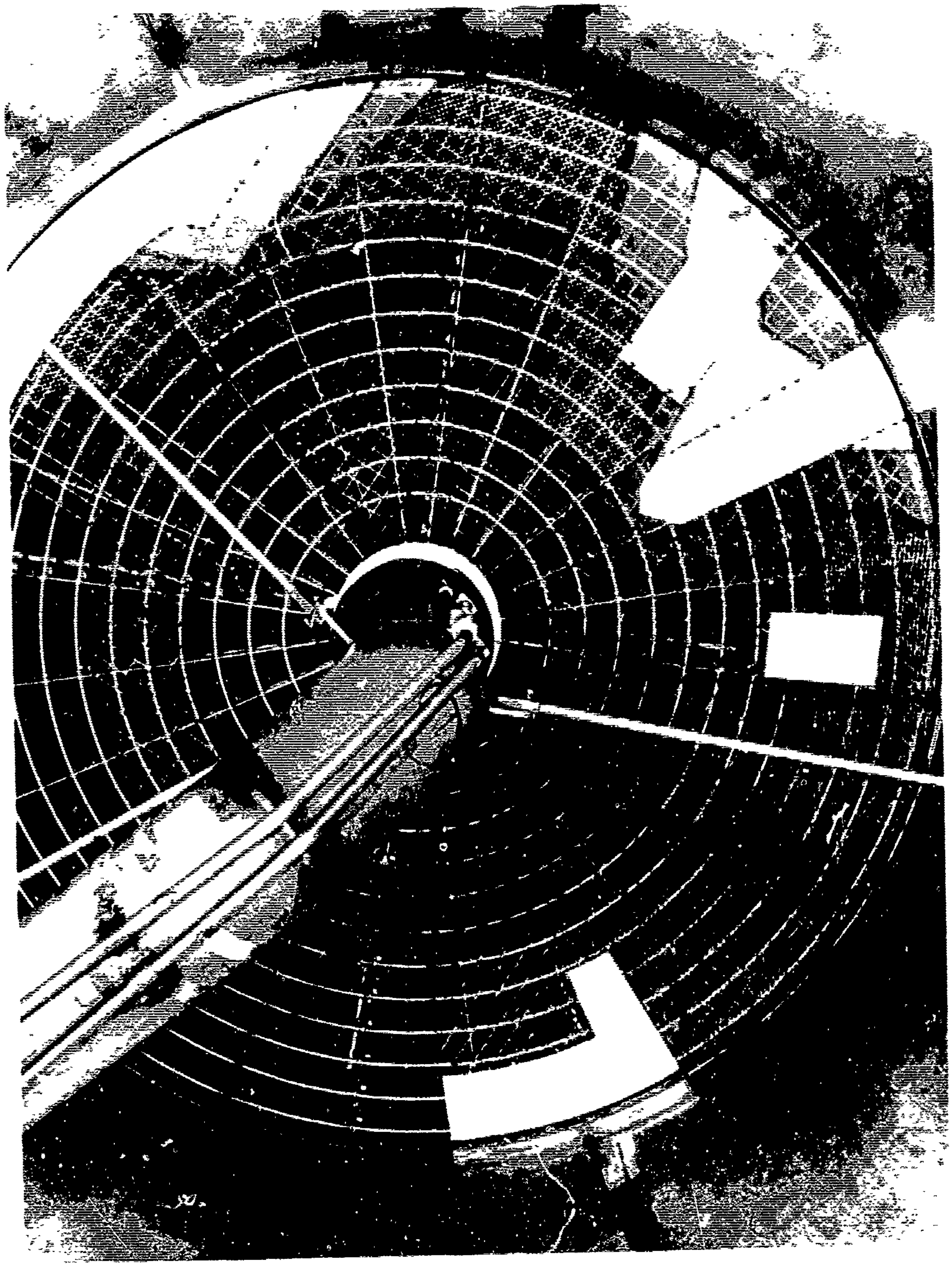


Figure III-B-3. Inlet Distortion Screen and Strain Gage Instrumentation Duct

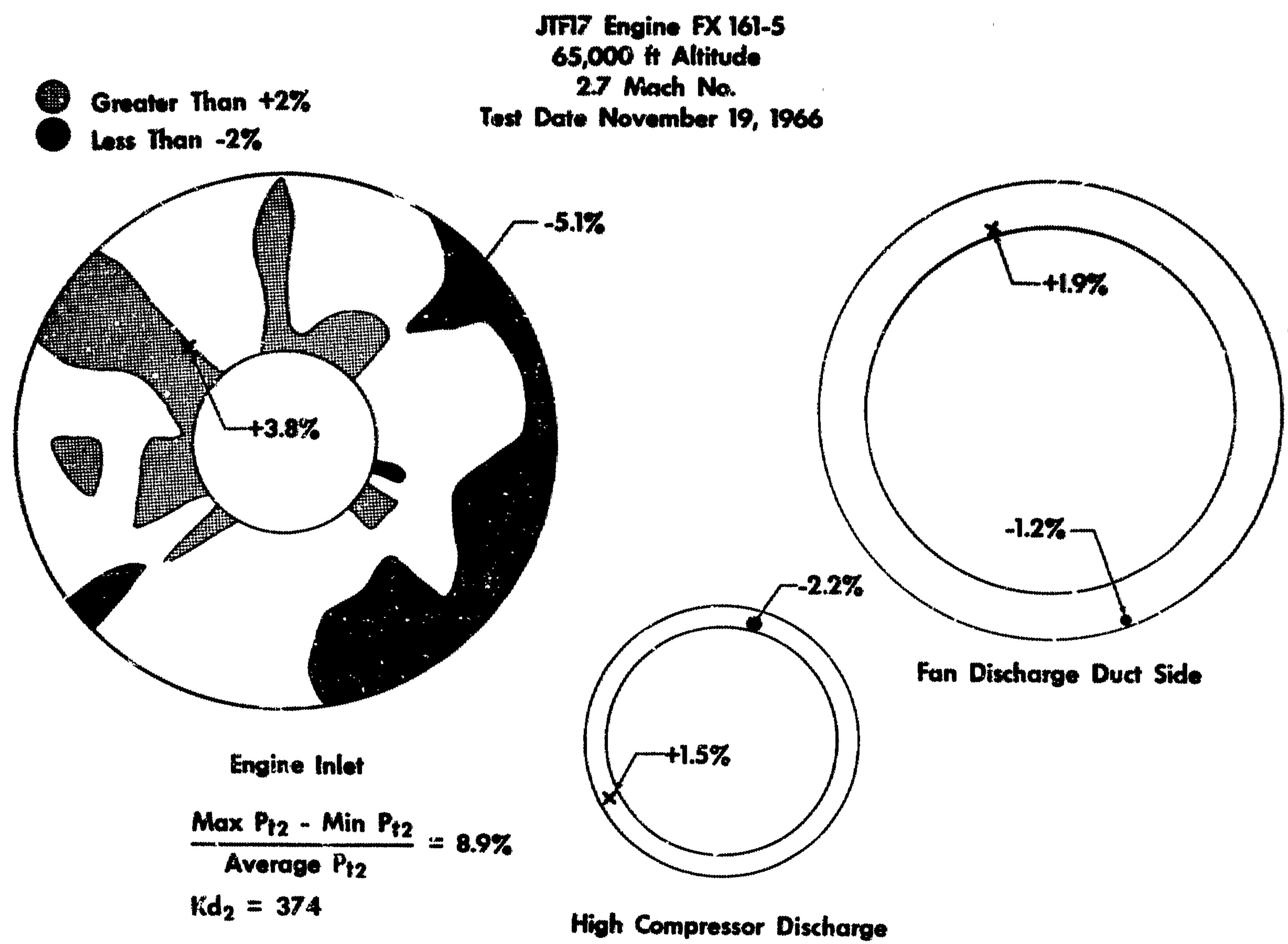


Figure III-B-4. Change in Pressure Profiles Because of Simulated Inlet Distortion

GS 4216

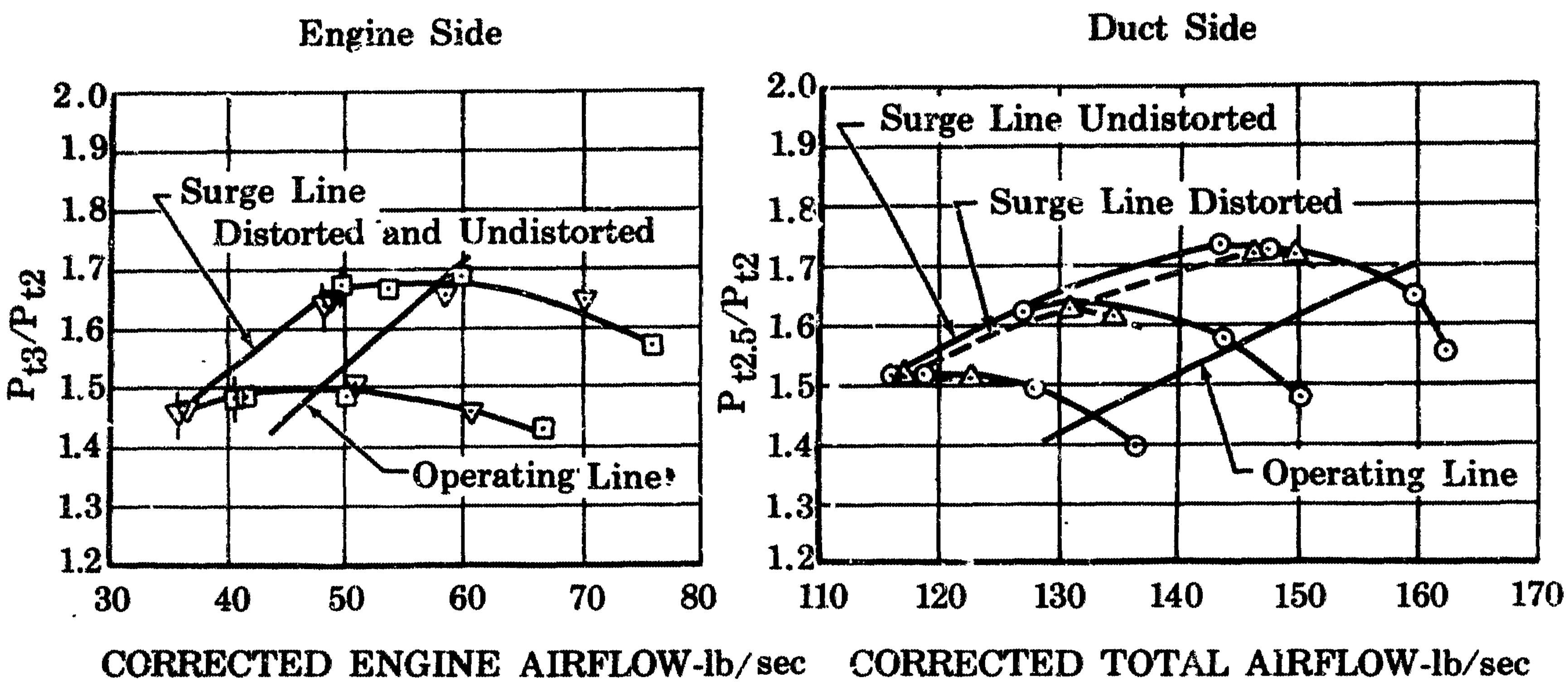


Figure III-B-5. JTF17 Effect of Inlet Distortion on Fan Surge Line for Two-Stage Fan Compressor Rig

FD 19038

FD 18986

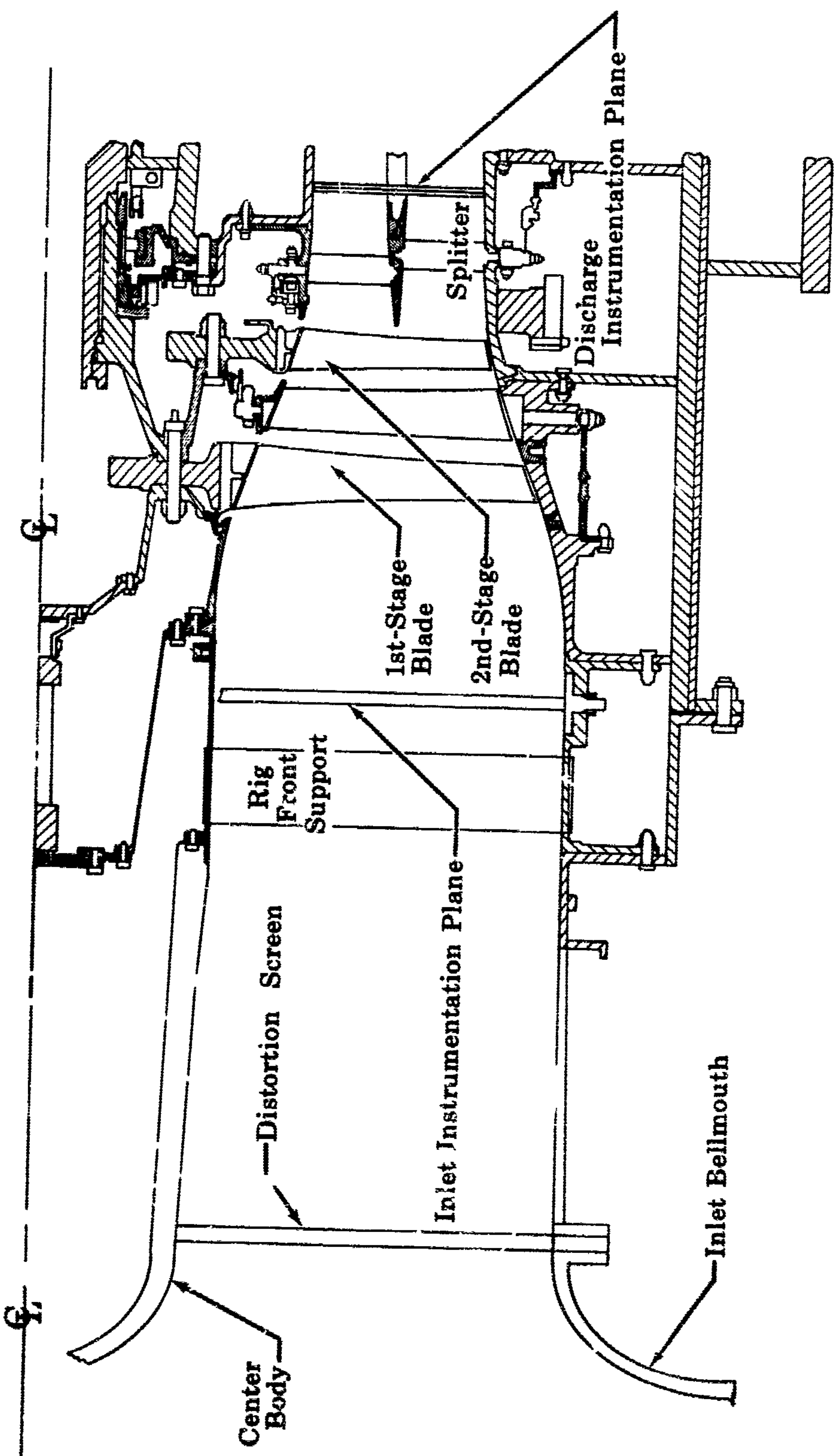


Figure III-B-6. Schematic of Fan Inlet Distortion Test

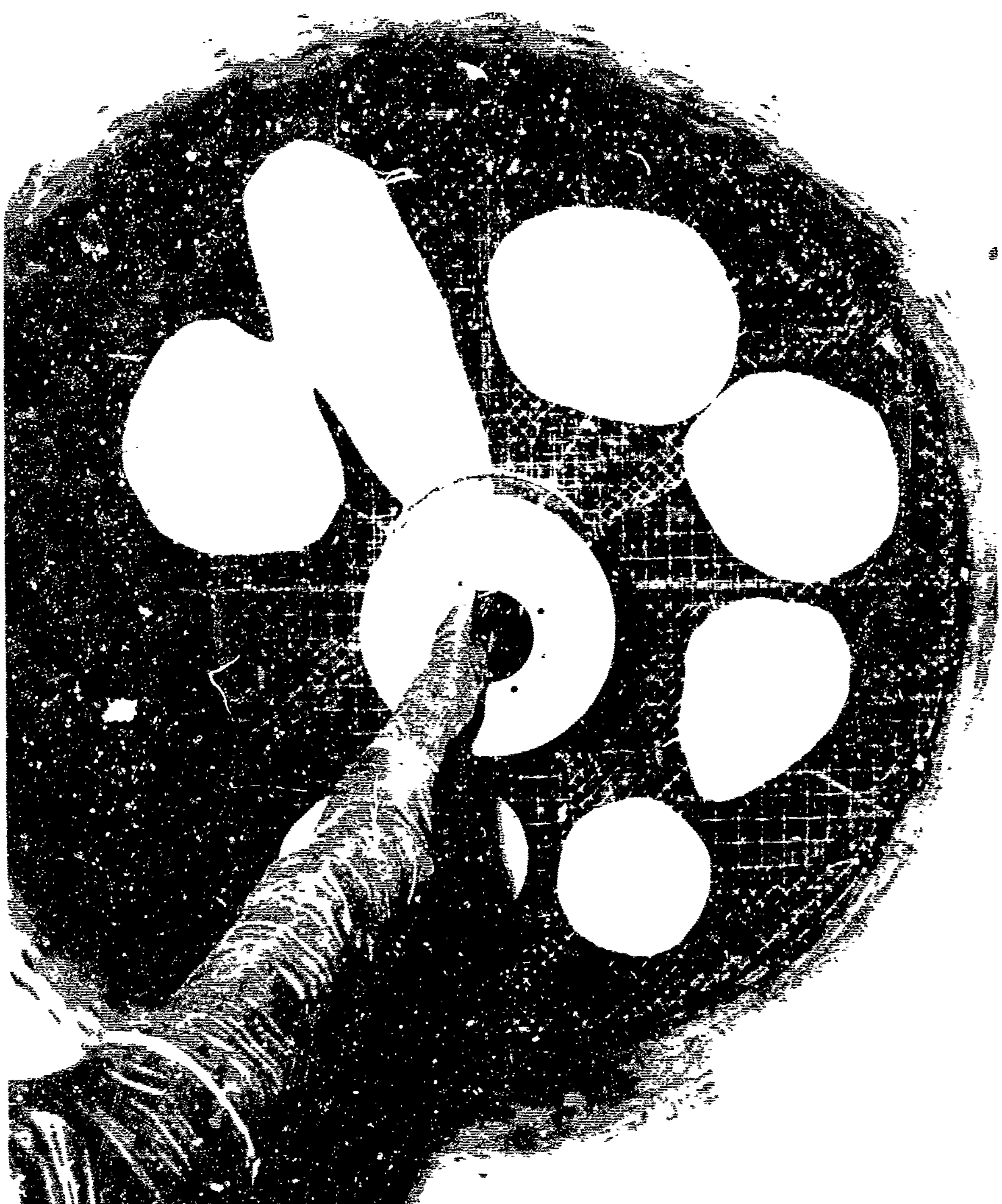
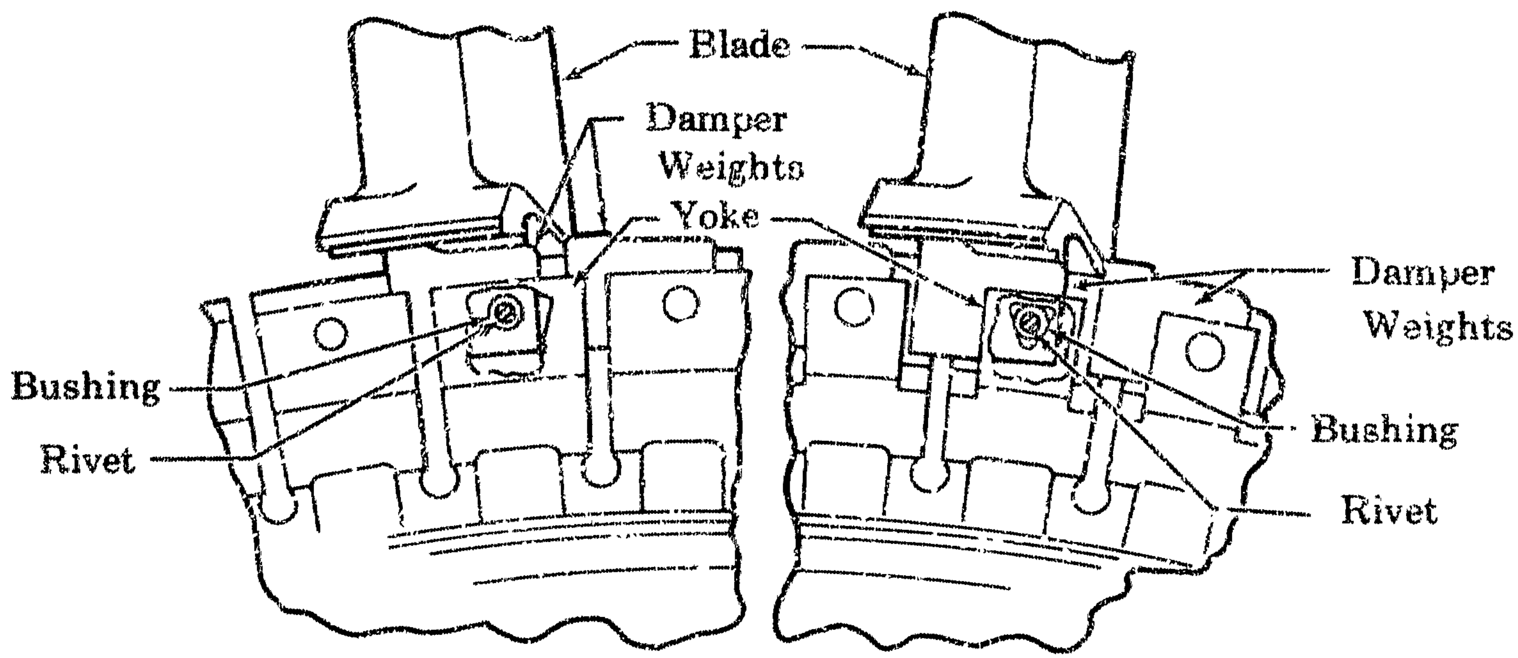


Figure III-B-7. Distortion Screen for 0.6-Scale Fan Rig   FE 65533



Original Cover Plate
and Damper Weights

Re-Operated Cover Plate
and Damper Weights

Figure III-B-8. 1st-Stage Turbine Blade Damper Modification

FD 19039

FE 64997

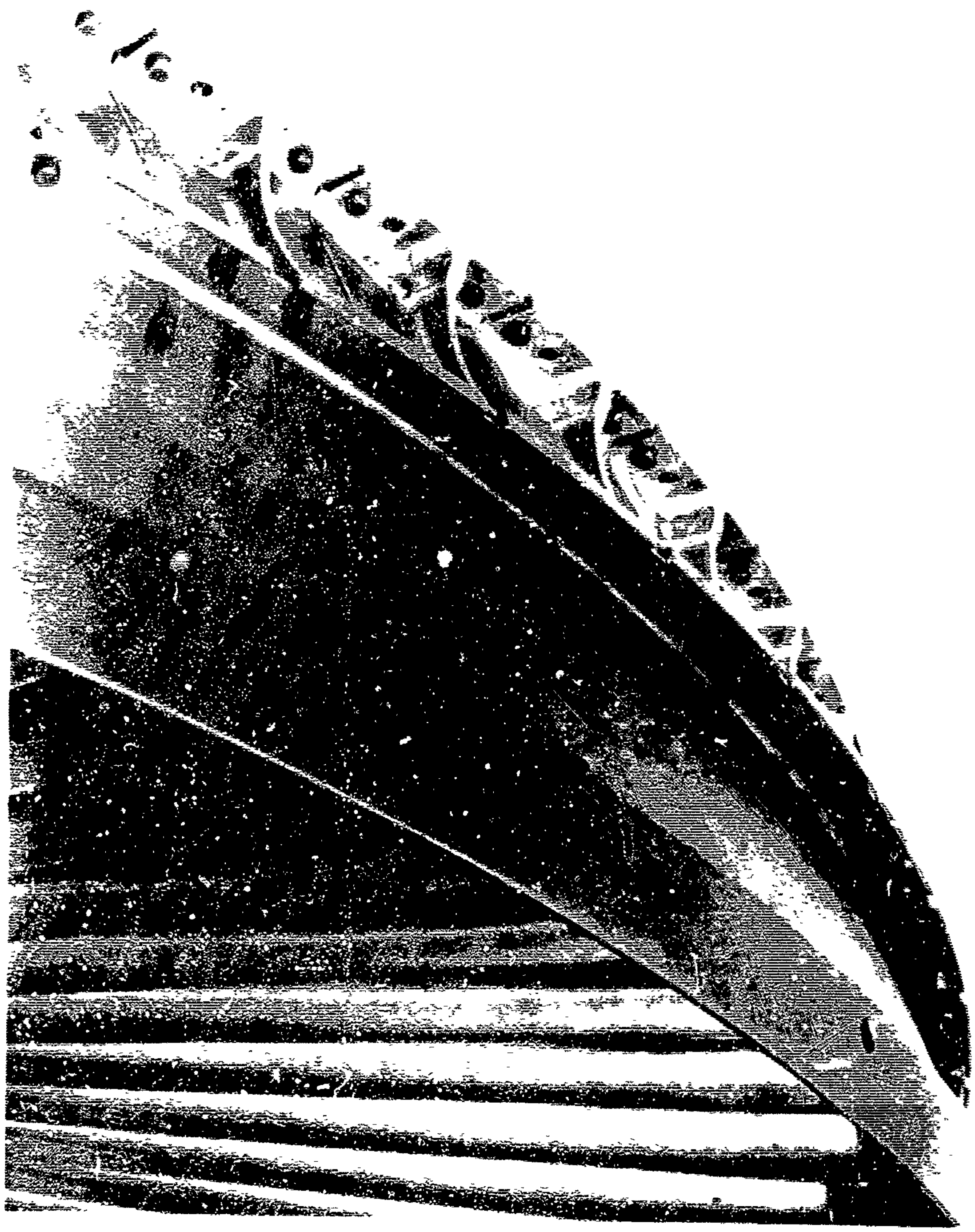


Figure III-B-9. Increased Strength Outer Fan Shroud

FD 17404

Figure III-B-10. Reworked Outer Fan Shroud Incorporating Bands for Additional Stiffness and Damping

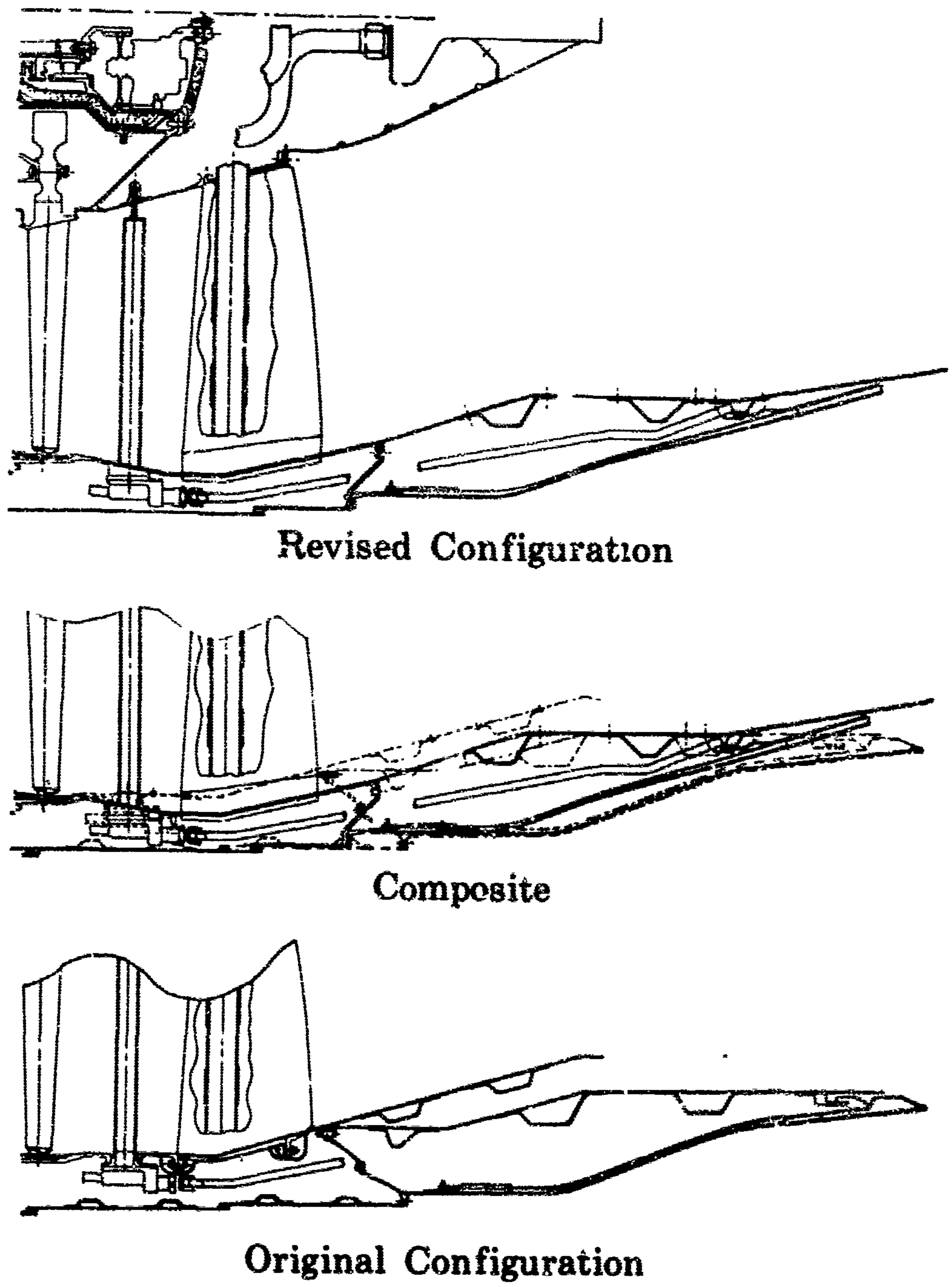


Figure III-B-11. Revised Turbine Exhaust Section and Gas Generator Exhaust Nozzle Contour FD 19035

DF 52503

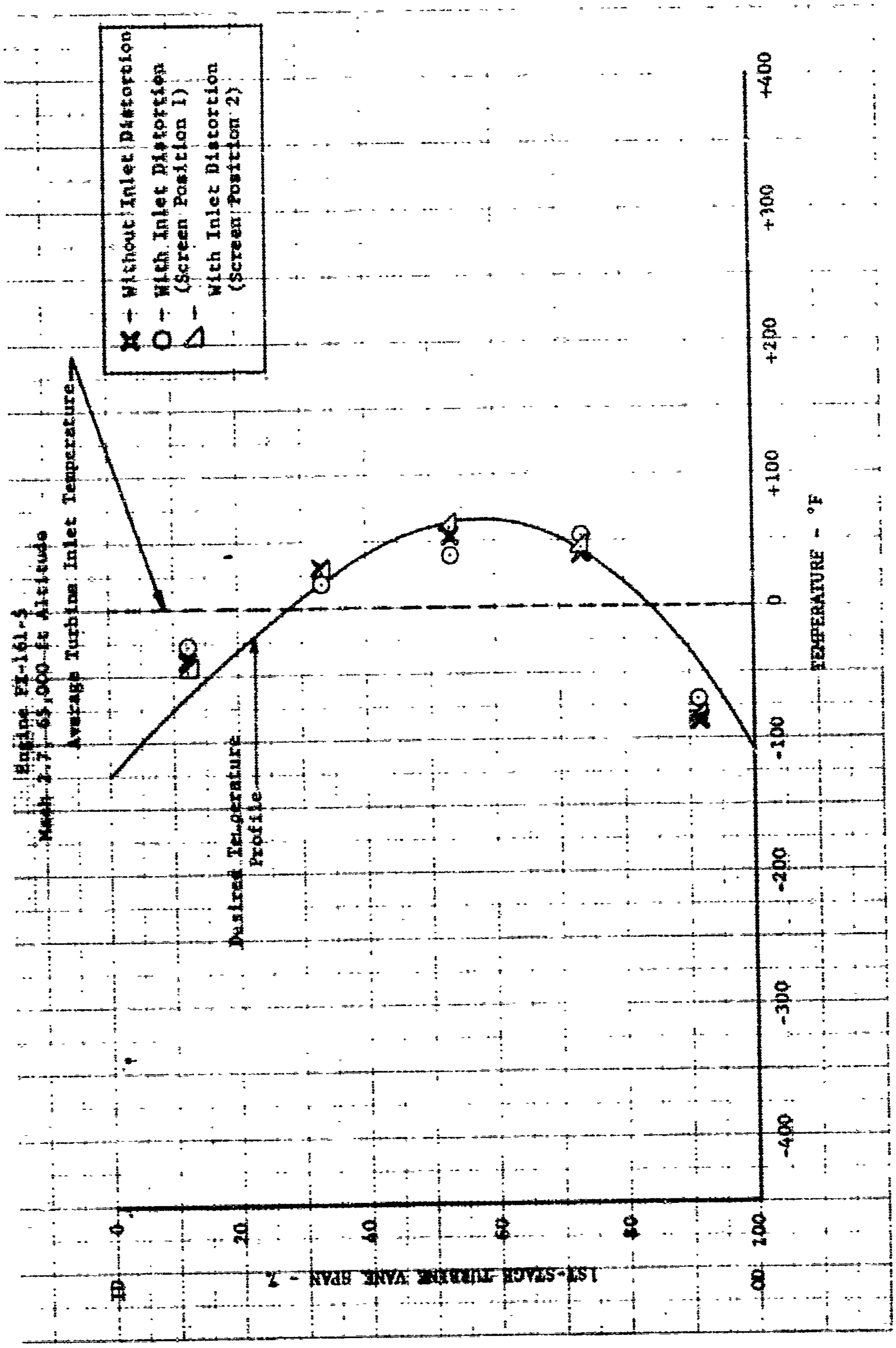


Figure III-B-12. Effect of Inlet Distortion on Turbine Average Radial Temperature Profile

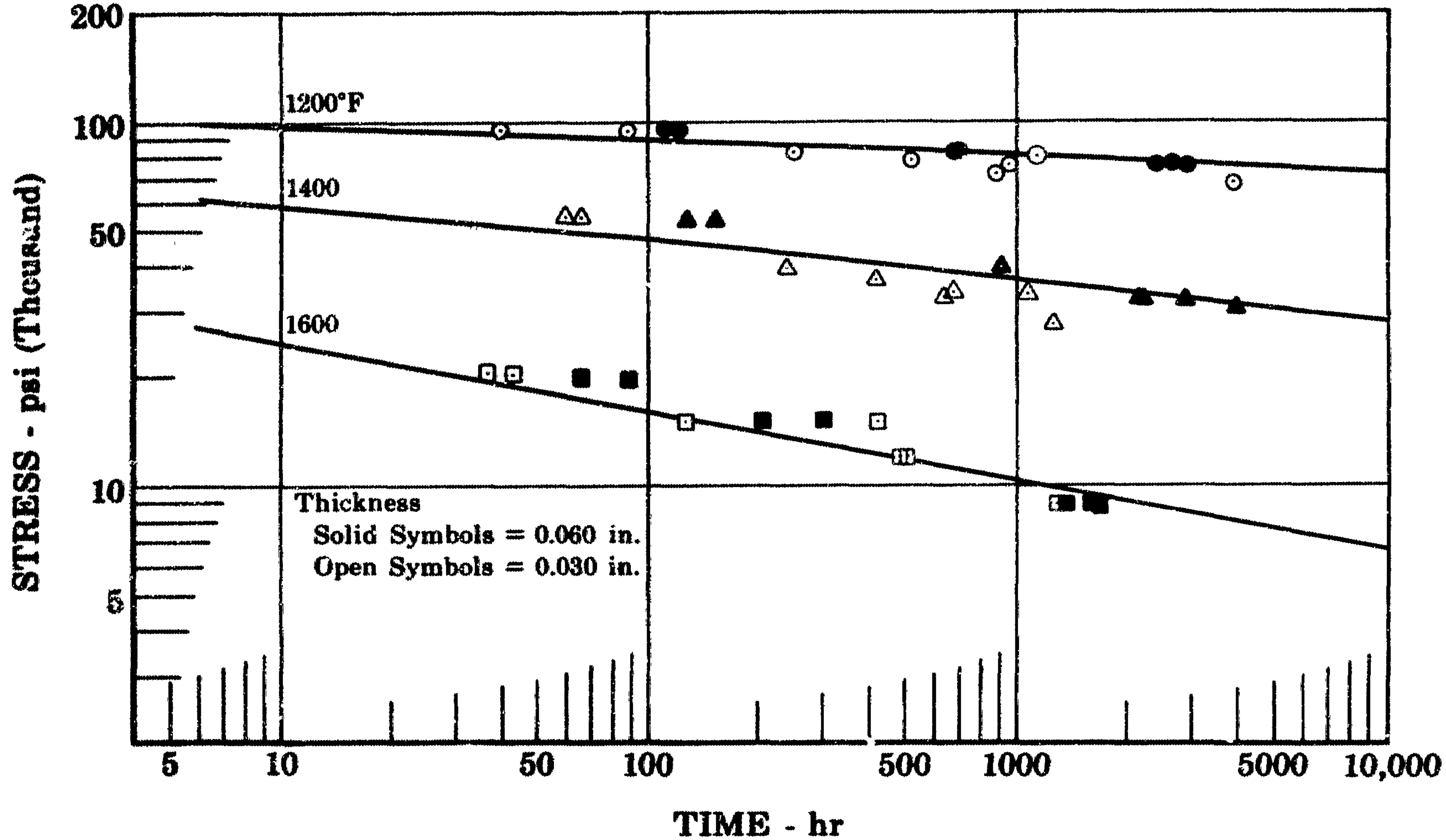


Figure III-B-13. Waspaloy Sheet (PWA 1030) Stress Rupture Test vs Design Curves

FD 15592F

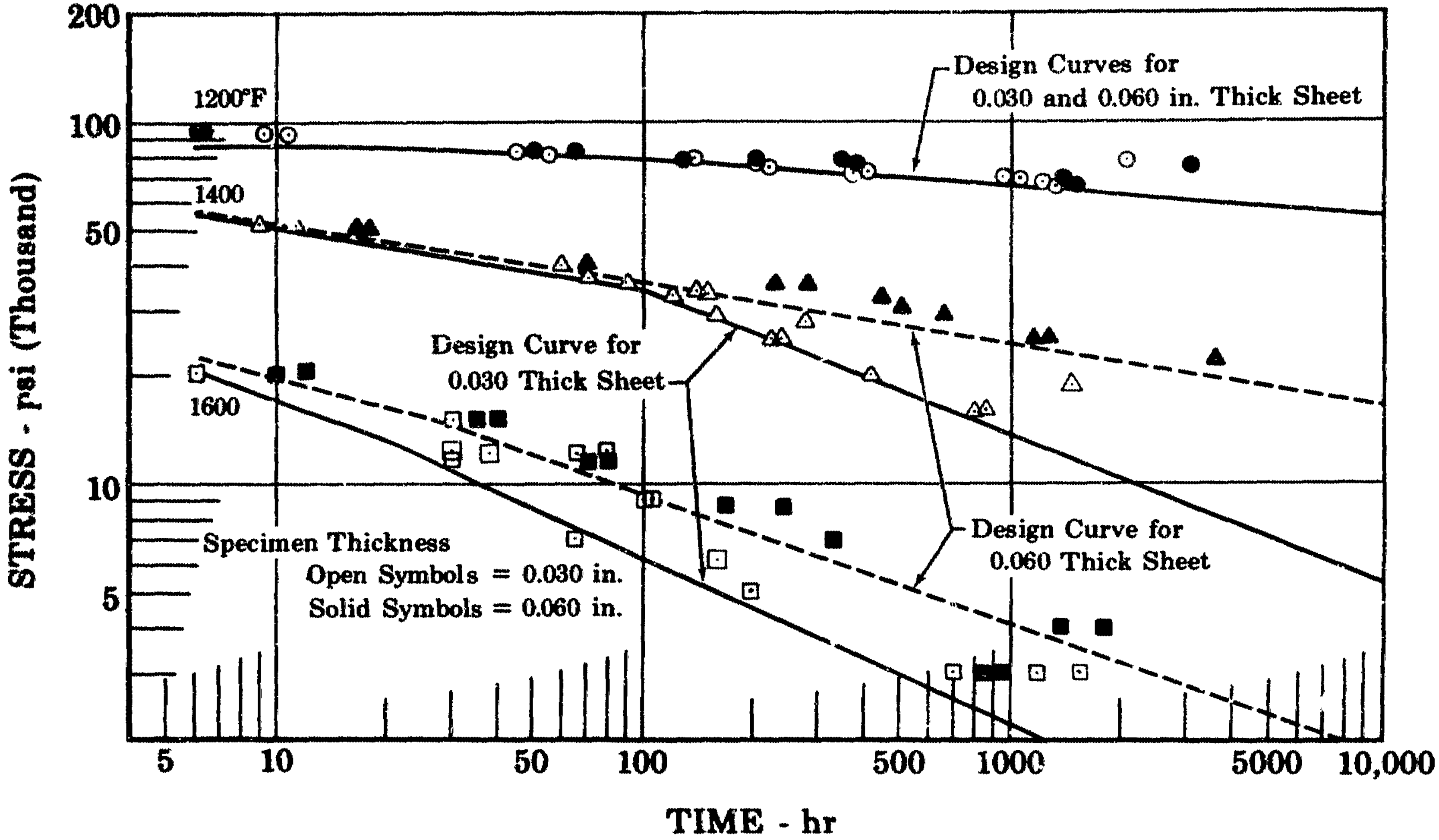
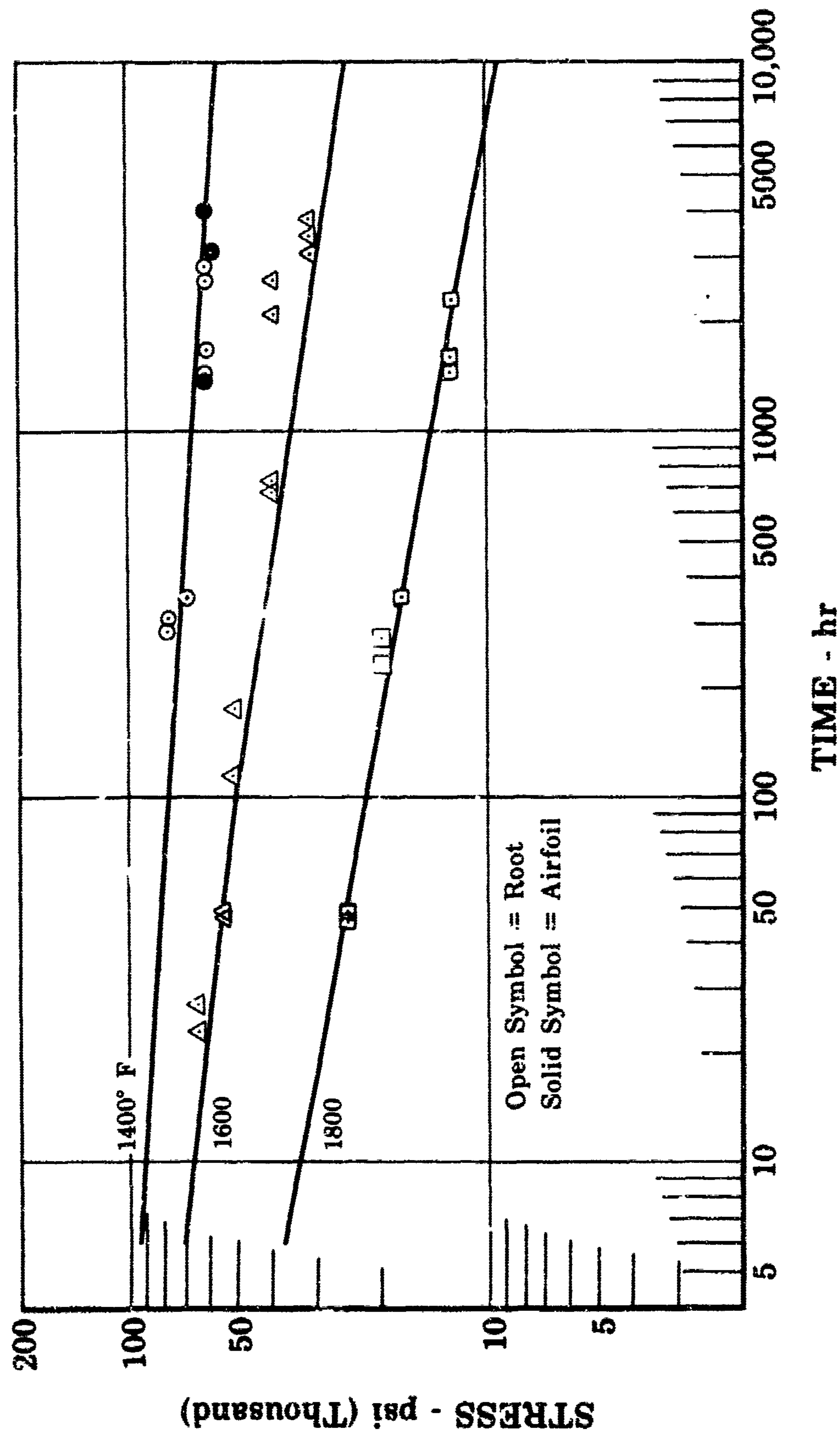


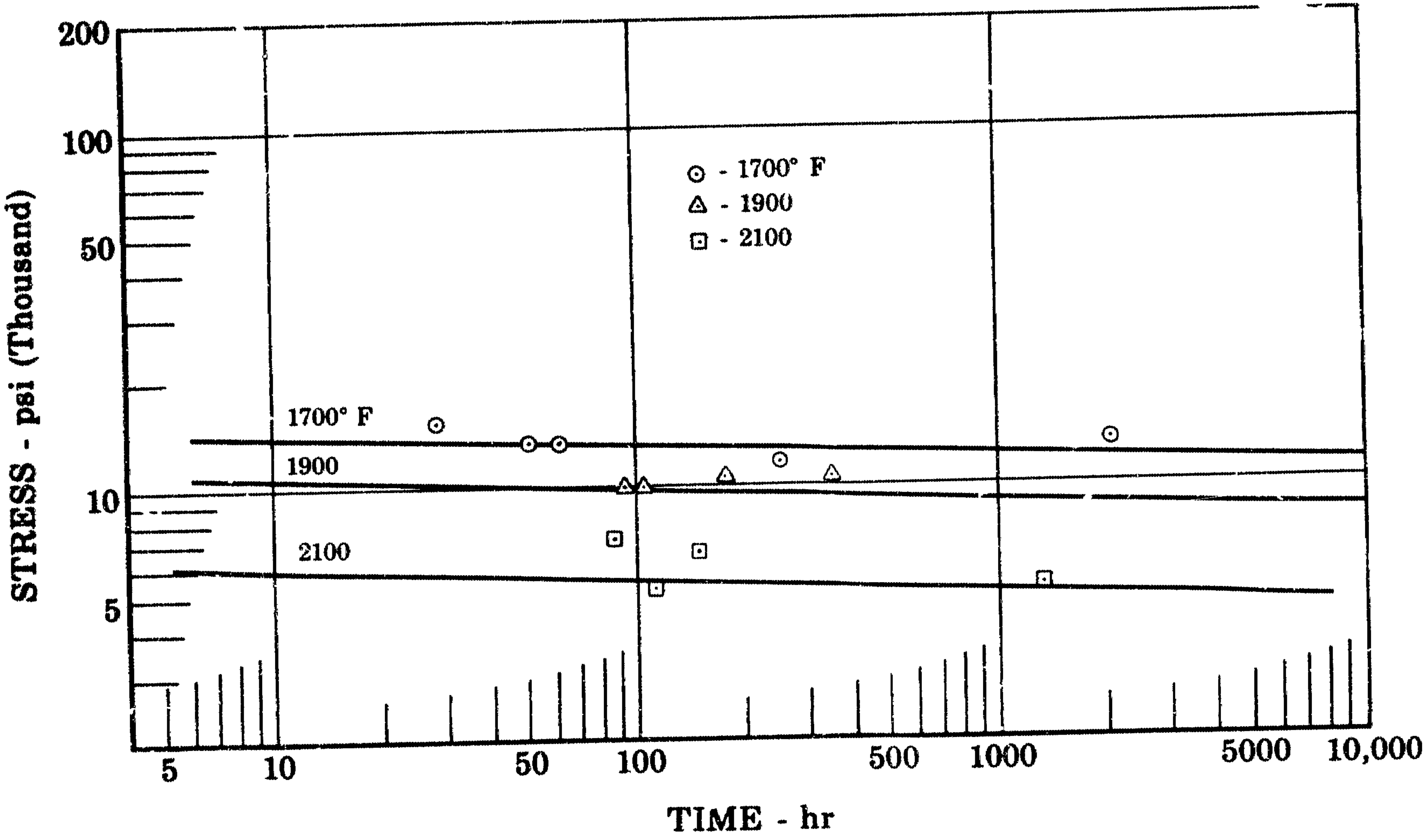
Figure III-B-14. Waspaloy Sheet (PWA 1030) 0.5% Creep vs Design Curves (Revised)

FJ 15563G



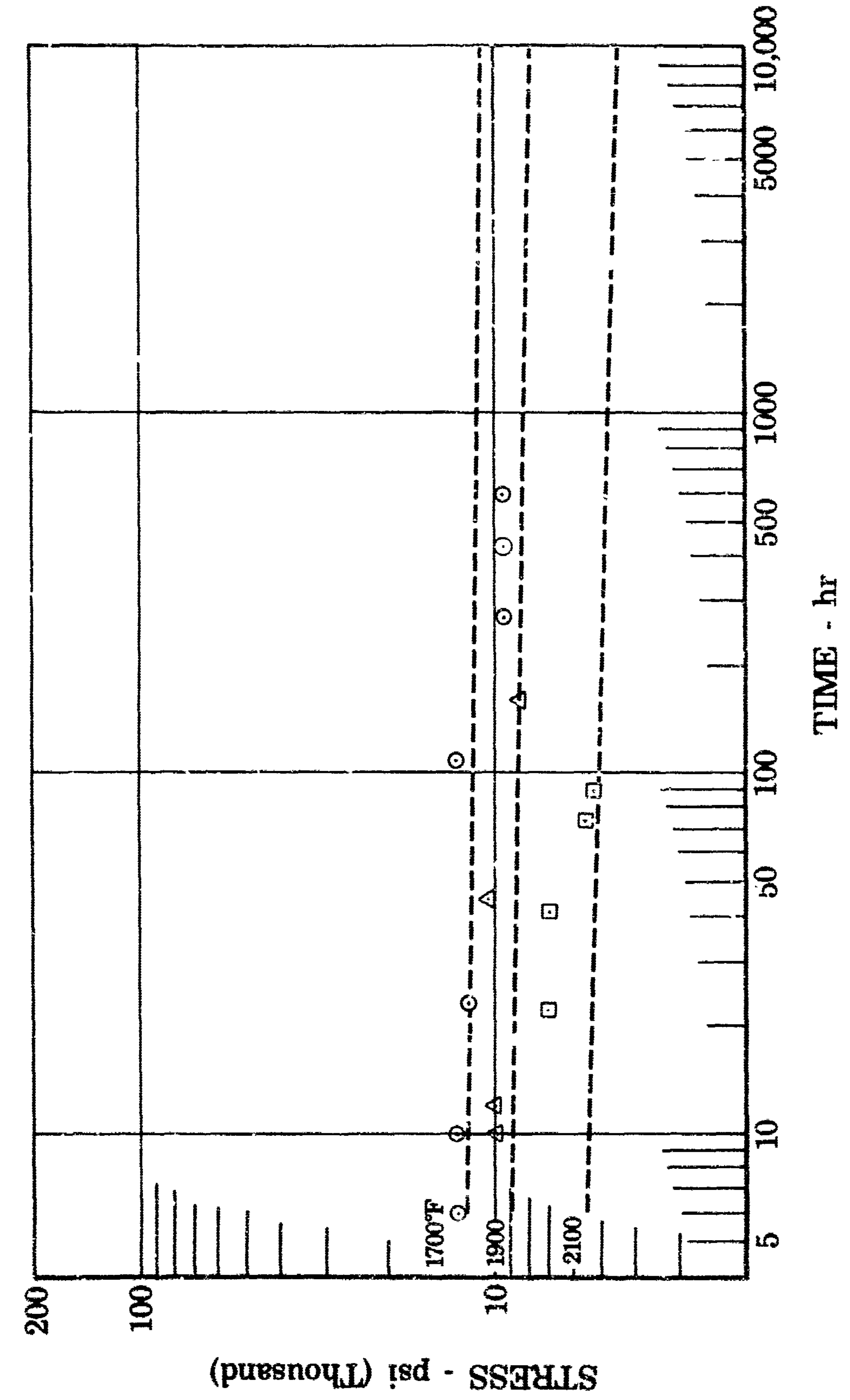
FD 15590F

Figure III-B-15. IN-100 (PWA 658) Stress upture Test vs Design Curves



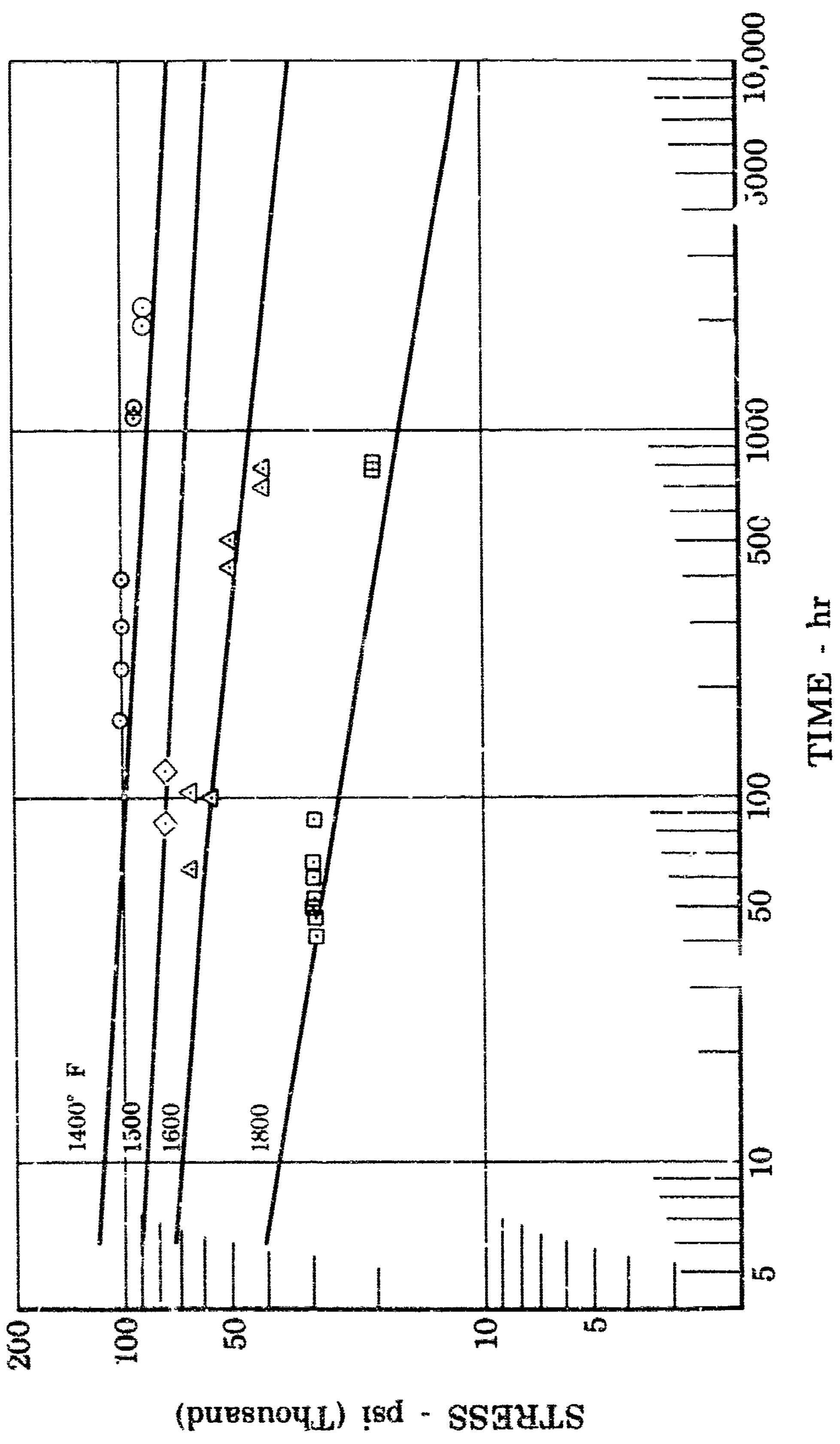
FD 15596D

Figure III-B-16. TD Nickel (PWA 1035) Stress Rupture Test vs Design Curves



FD 18841A

Figure III-B-17. TD Nickel (PWA 1035) 0.5% Creep vs Design Curves



FD 17293C

Figure III-B-18. PWA 664 Stress Rupture Test vs Design Curves

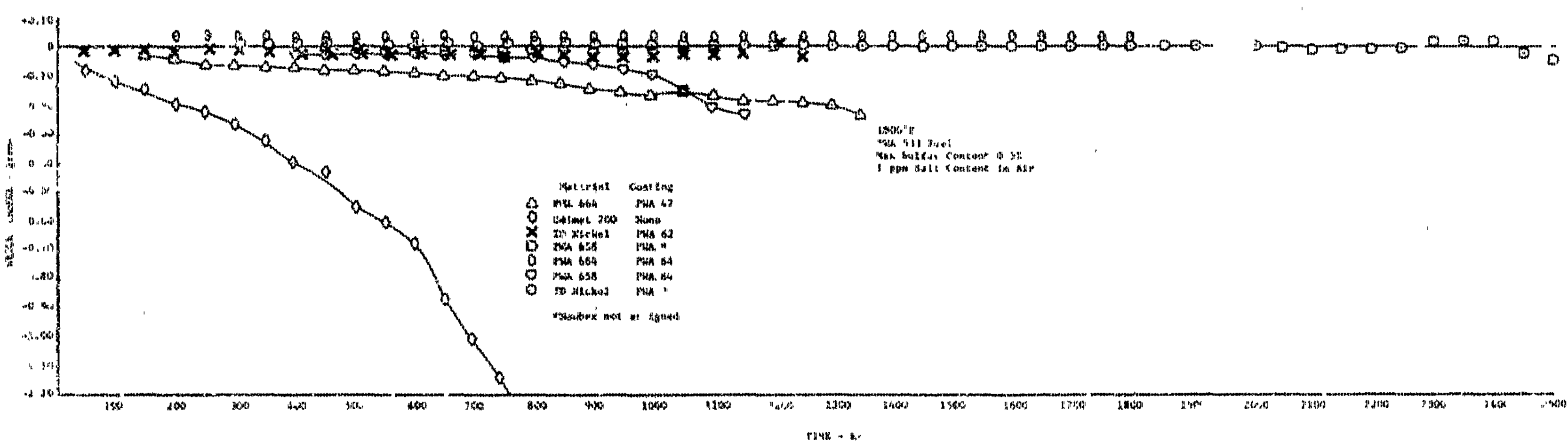


Figure III-B-19. Summary of Sulfidation Testing on Candidate Materials and Coatings

DF 47360D

Figure III-B-20. Condition of SST Alloys Following Sulfidation Testing

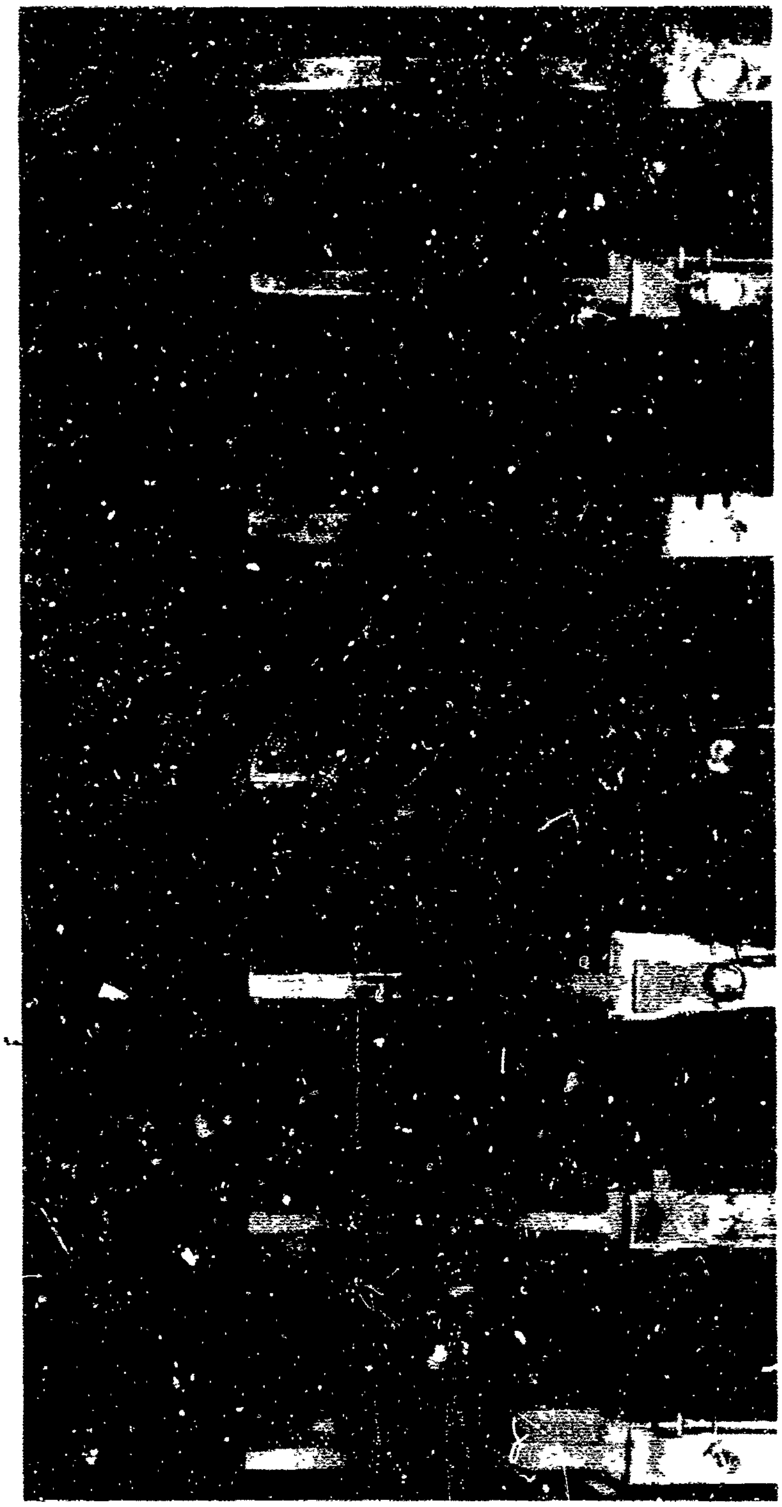


Figure III-B-21. Condition of SST Alloys Following Oxidation - Erosion Testing

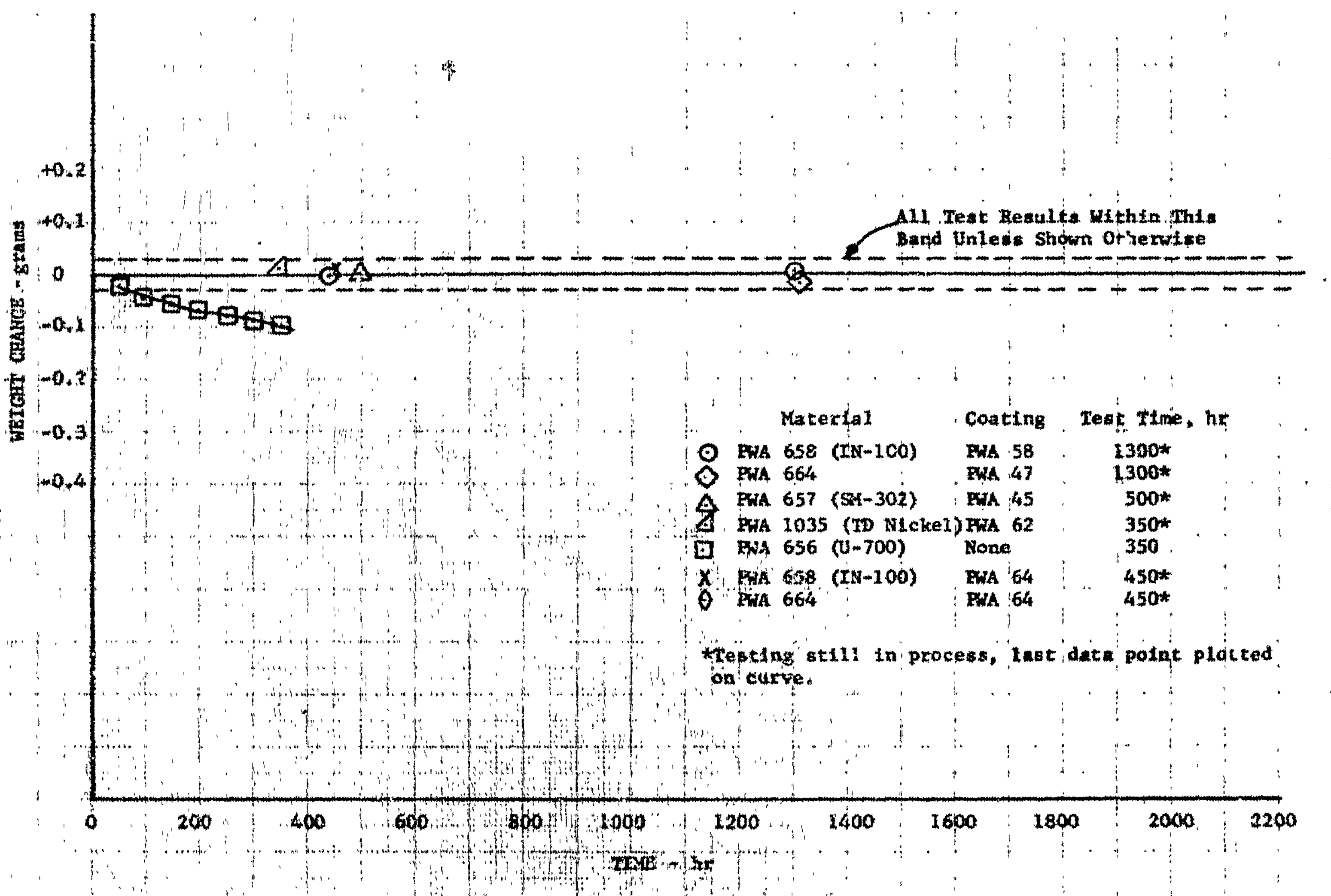


Figure III-B-22. Oxidation - Erosion Test Data Obtained at 1800°F Metal Temperature

DF 51765A

C. COMPRESSOR

1. 0.6-Scale Fan Rig

	November	Phase II-C Total
Test Time	103.00 hours	562 hours

Build No. 11 of the 0.6-scale fan rig completed its overall performance calibration and was tested with inlet distortion during November.

Build No. 11 incorporated the build No. 5 configuration fan with a 7-degree overcamber of the 1st-stage vane root. It was intended that overcamber of the 1st-stage vane root would improve the 1st-stage root match and increase the root stall margin. Although the engine side surge line was slightly improved, the overall performance of build No. 11 was essentially that of build No. 5 with no change resulting from the 1st-stage vane overcamber. The performance of build No. 11 relative to the build No. 5 surge line is illustrated by the compressor maps of figures III-C-1 and III-C-2.

Fan inlet distortion testing was accomplished through the use of screens installed in a straight cylindrical test section approximately one duct diameter upstream of the 1st-stage blades. A schematic of the test configuration is shown in reference figure III-B-6. Twenty-four total pressure rakes upstream of the fan inlet were used to define the inlet pattern. A similar set of rakes at the fan discharge were used to determine the attenuation characteristics of the fan.

The distortion screen used is shown in reference figure III-B-7. The distortion factor (K_{d2}) of the tests was 15% above the maximum anticipated for Mach 2.7 cruise operation. As shown in reference figure III-B-5, the surge margin on the engine side was unaffected by the simulated distortion and lowered only 3% on the duct side. The fan attenuated the distortion in passing through the two fan stages. No indication of flow instability or stall was encountered. Details of the distortion test analysis are contained in Inlet System Compatibility, section III-K, of this month's report.

The redesigned 1st- and 2nd-stage blades scheduled for testing in December are now assembled in the 0.6-scale fan rig. The purpose of the build No. 12 configuration is to rematch the compressor stages for peak performance. The 1st-stage blades are a revised version of the build No. 10 rotor that failed because of cracks resulting from rework to

overcamber the build No. 7 blades. The 2nd-stage blades incorporate a closed leading edge root and an opened leading edge from 30% span, relative to the build No. 7. This rotor will match the stages for high duct pressure ratio and have the capability to operate to lower flows. Test results from build No. 12 are expected the 1st week in December.

2. Full-Scale High Compressor Rig

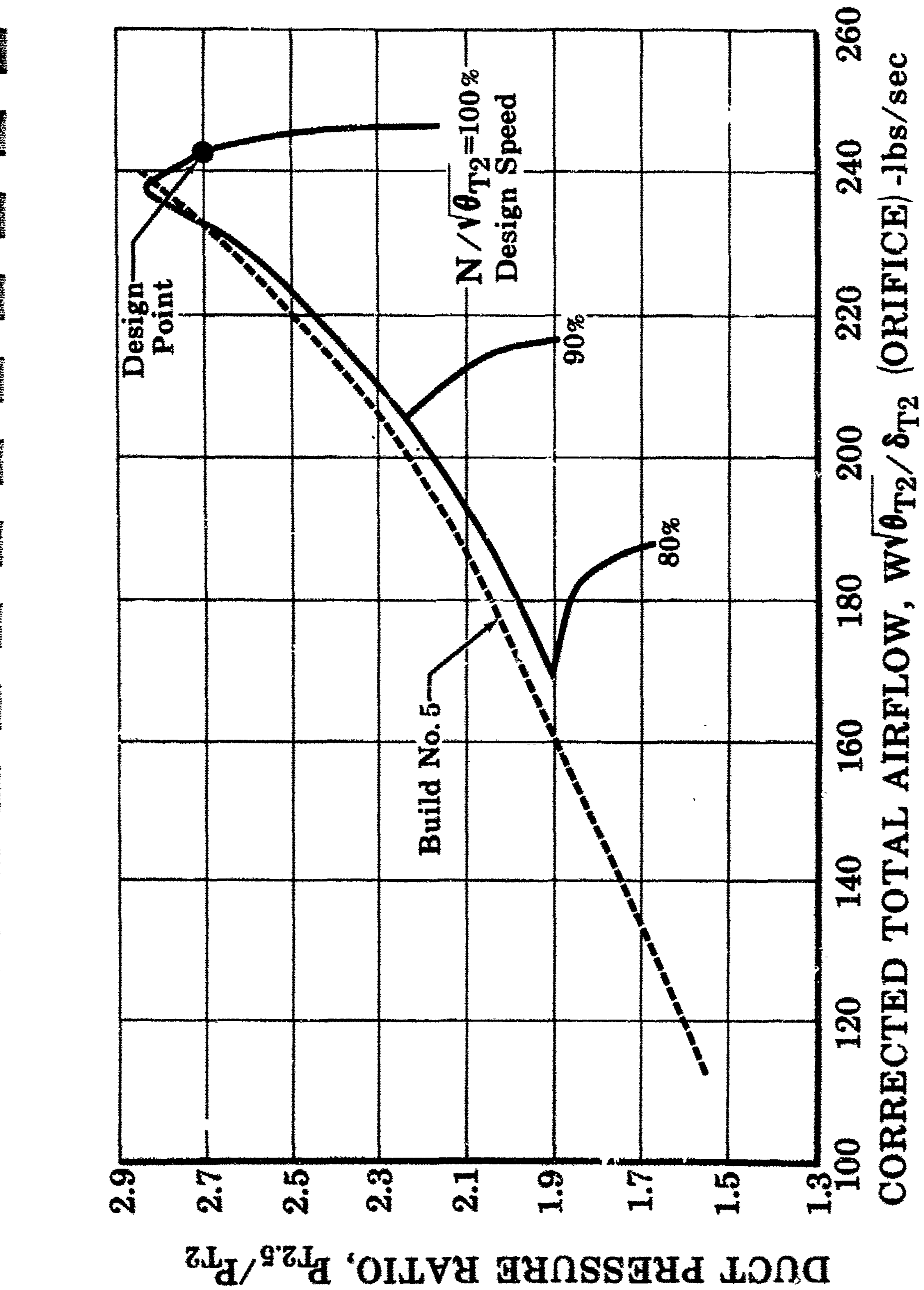
	November	Phase II-C Total
Test Time	12.92 hours	114.50 hours

Rig testing of the prototype JTF17A-21 compressor was completed early in November. The compressor rig, ready for test, is shown in figure III-C-3. The performance met or exceeded the airflow, efficiency, and pressure ratio requirements for the JTF17A-21 production rating. The excellent performance of the prototype compressor is illustrated by the data presented in reference figure III-B-1. Reference figure III-B-2 illustrates the improved surge characteristics relative to the current Phase II-C high compressor requirements and builds No. 3 and No. 5 of the JTF17A-20 compressor.

The prototype compressor is a redesign of the JTF17 high compressor to improve the surge margin of the build No. 5 compressor and to meet the requirements of the JTF17A-21 engine. The rig tested is aerodynamically identical to the compressor presented in the 6 September, Phase III proposal and was tested with interstage bleed and with only the inlet guide vane variable. The redesign, based on results of Phase II-C testing, has three major changes from the earlier compressors. First, the camber of blades and vanes has been modified to flatten the stage flow and pressure profiles within the compressor. An example of the camber change in blades is shown by a comparison of the 5th-stage blades of the prototype compressor and of build No. 5, as shown in figure III-C-4. The compressor work has been redistributed in the design to reduce the loading of rear stages. This design change is illustrated by plots of rotor and stator D factor, figure III-C-5. Compressor chords have been selectively increased, primarily in vanes. These changes are shown in figure III-C-6 for rotor and stator.

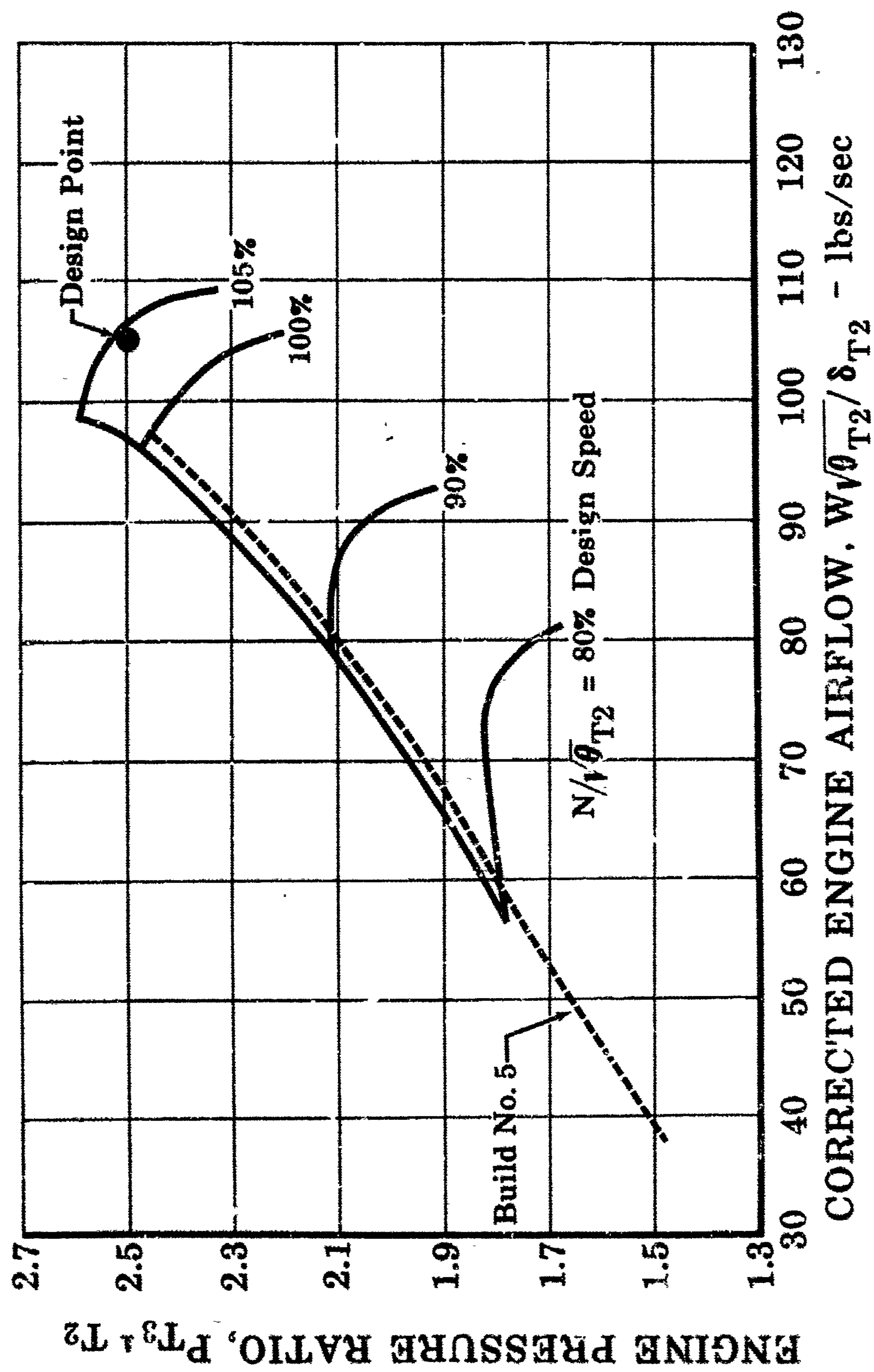
No further compressor rig testing is planned for Phase II-C. The major effort will be directed at engine testing of the compressor. Although the prototype rig parts were designed for rig testing only, the

disks and blades are adequate for sea level running. As soon as possible, new vanes and cases will be manufactured to replace the rig 347 stainless steel cases with PWA 1010 cases, structurally adequate for engine testing. Engine testing with the improved compressor is expected early in December.



FD 18987

Figure III-C-1. Fan Stream Performance, Two-Stage Fan Compressor Rig, Build No. 11



FD 18988

Figure III-C-2. Engine Stream Performance, Two-Stage Fan Compressor Rig, Build No. 11

FD 19065

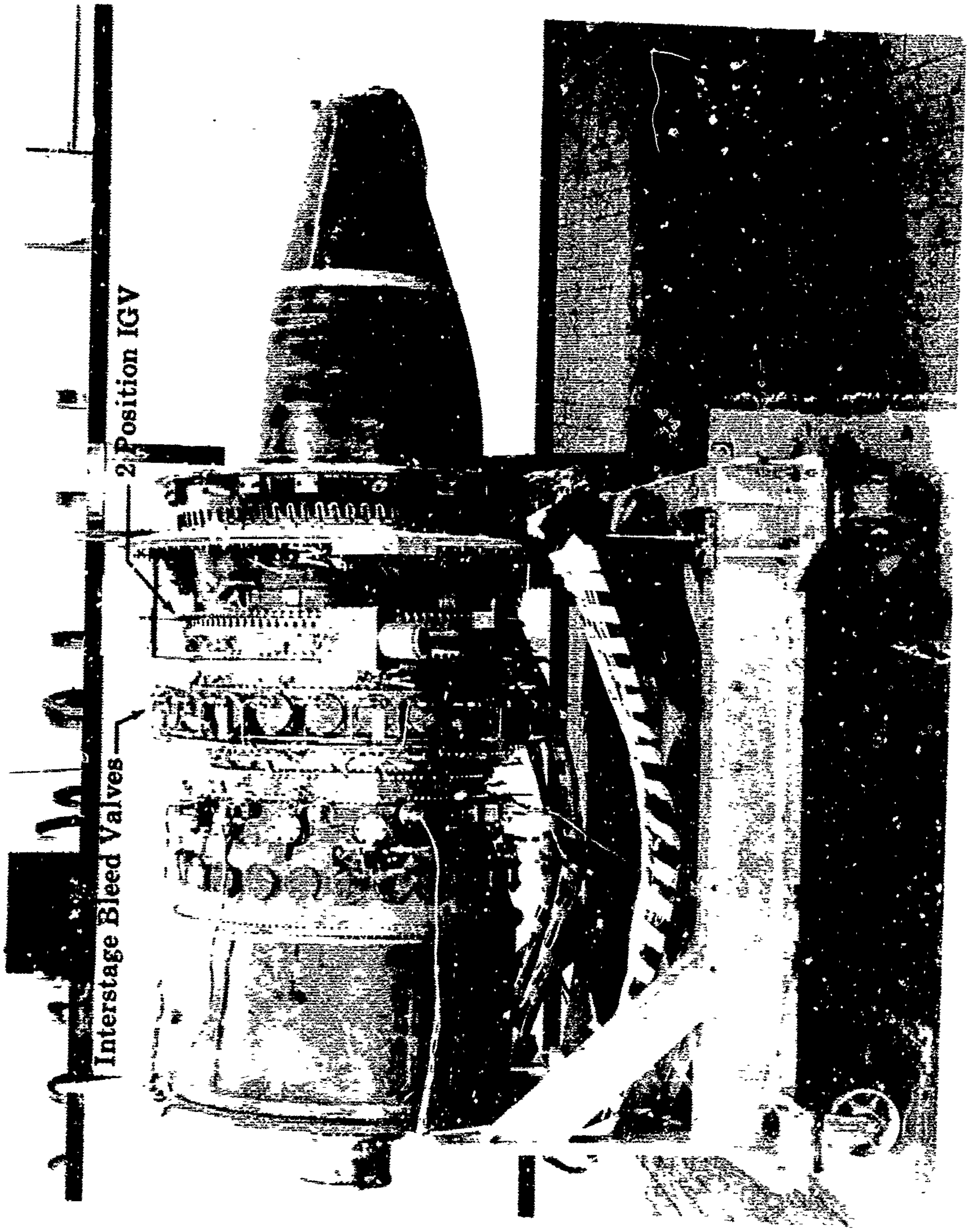


Figure III-C-3. JTF17 Prototype Compressor Rig

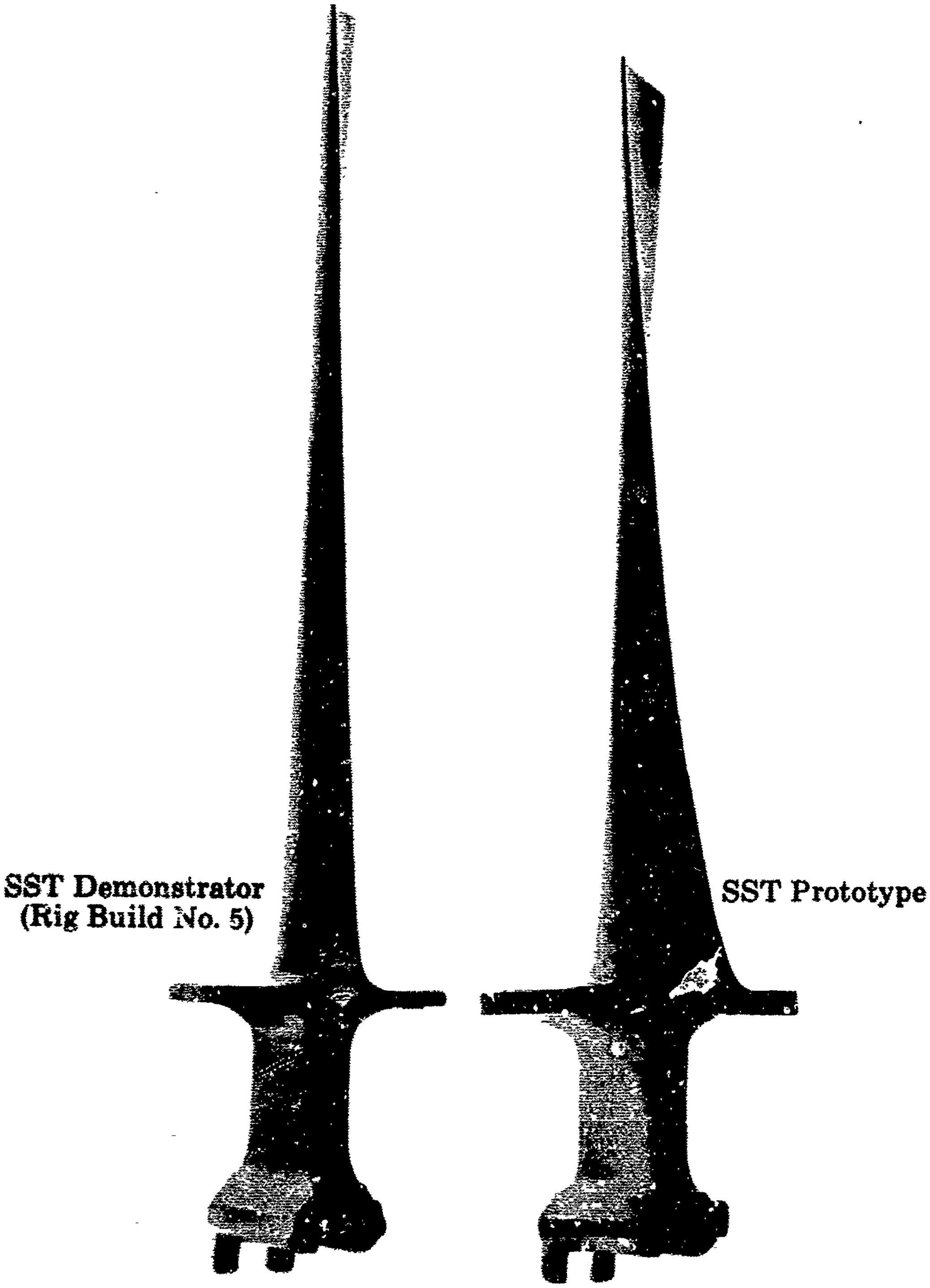


Figure III-C-4. JTF17 5th-Stage Compressor Blade Comparison - Trailing Edge View

FD 19066

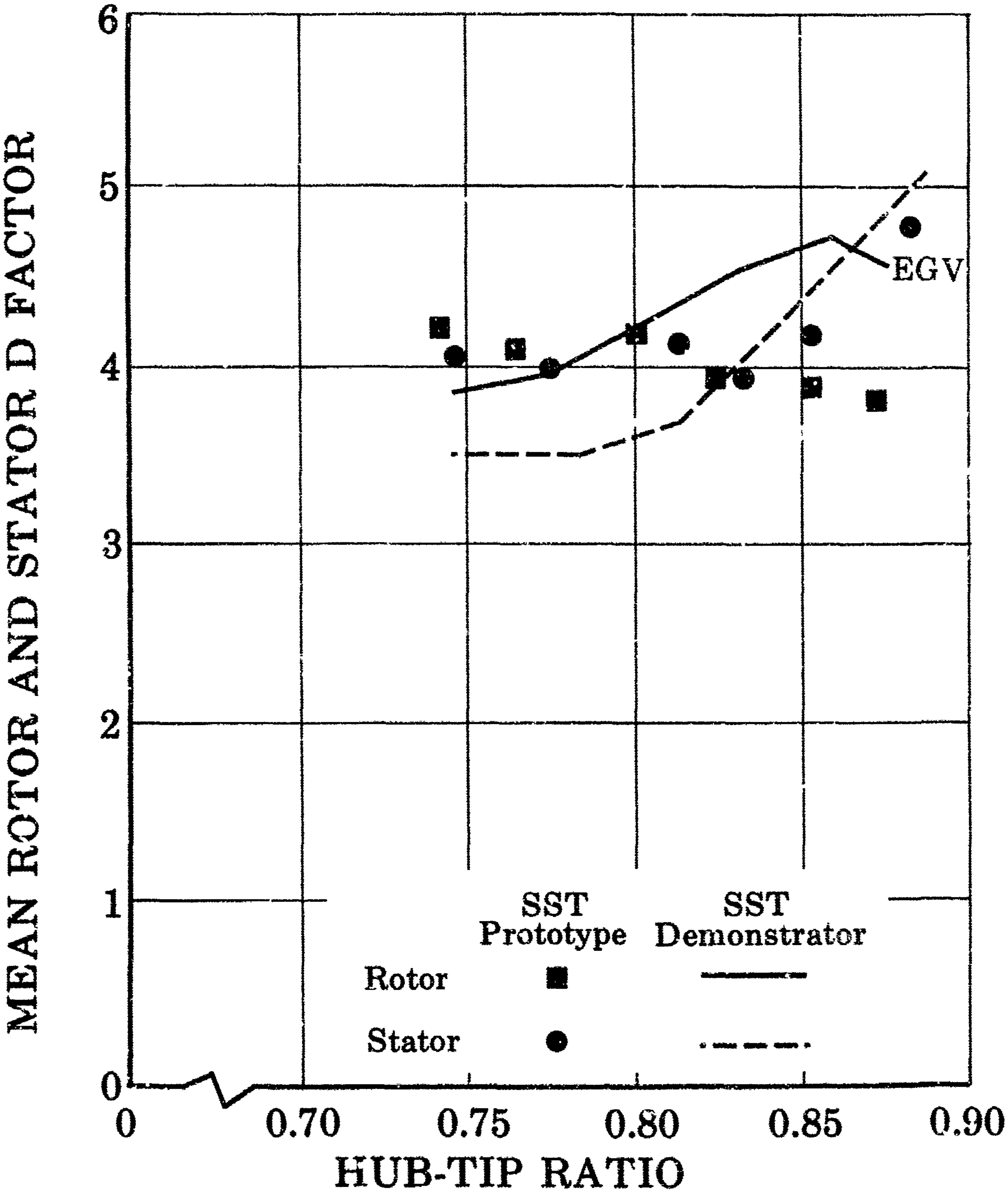


Figure III-C-5. Rotor and Stator D Factor vs Hub-Tip Ratio FD 19034

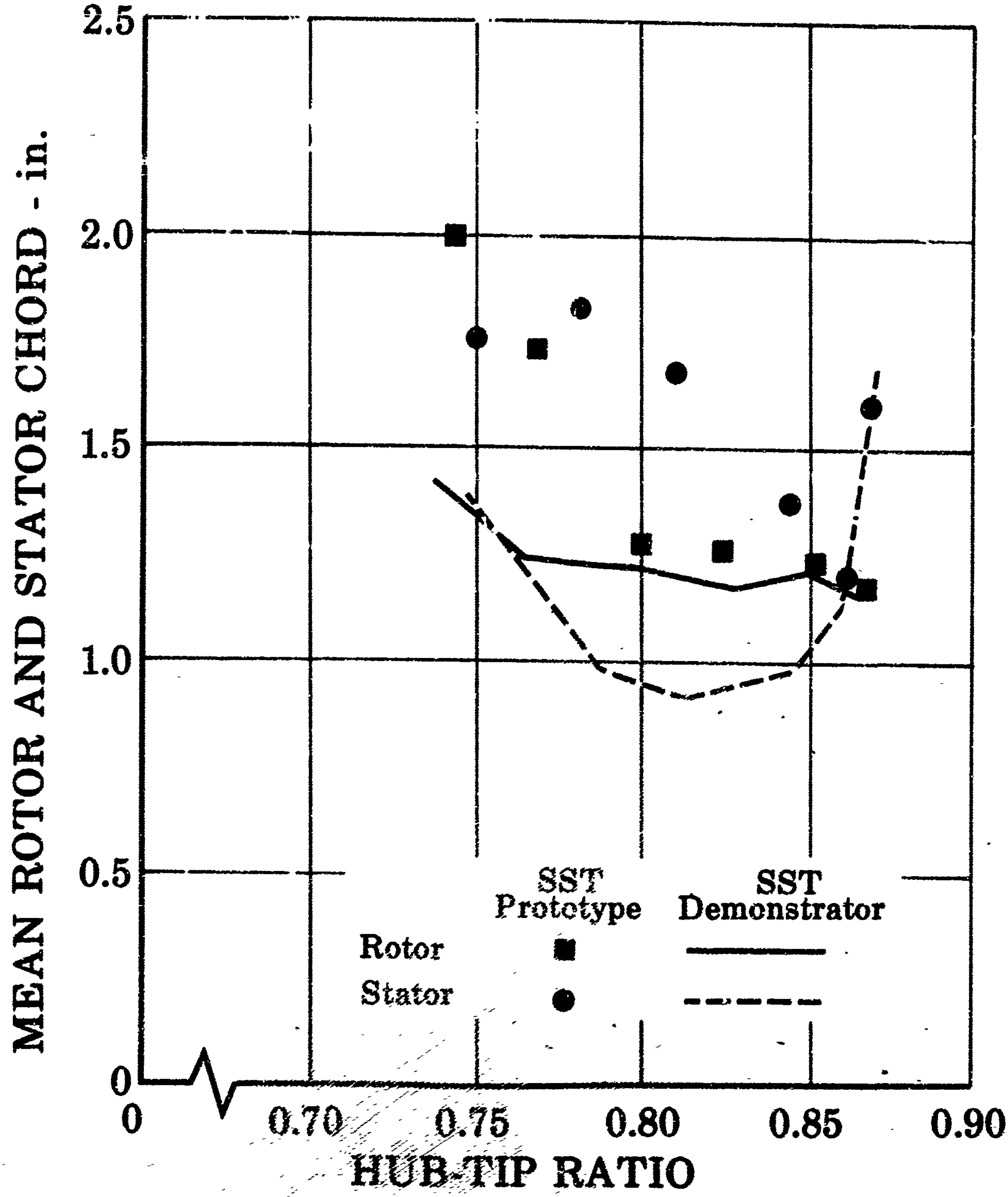


Figure III-C-6. Rotor and Stator Chord vs Hub-Tip Ratio FD 19033

D. PRIMARY COMBUSTOR

	Full-Annular Rig Test Time	
	November	Phase II-C
JTF17	0	5.36 hr
Related Technology	0	65.8 hr

1. Engine Combustor Testing

Testing of the primary combustor continued on engine FX-161-5 at altitude conditions.

Engine FX-161-5 accumulated 3.68 hours of Mach 2.7 and 65,000 feet testing at cruise turbine inlet temperature during November for a total of 14.27 hours. Refer to section III-B for additional significant test times. The general condition of the primary combustor and the transition duct was good. This combustor with 87.41 hours is suitable for continued testing. The primary combustors in engines FX-162 and FX-163 did not accumulate any testing during this report period.

2. Full-Scale 120-Degree Segment Rig

Testing on the primary combustor was continued to investigate diffuser splitter configurations for possible incorporation in the JTF17 engine. The configurations were tested for a total of 17.53 hours in November. The tests included blockage of the ID and OD diffuser passages to reduce the expansion area ratios, removal of the center wedge of the original splitter, and forward extension of the original splitter.

3. P_{T5} Instrumentation Calibration

A program has continued on the vane cascade rig to develop improvements in the combustor discharge pressure instrumentation. The original pressure instrumentation in the leading edge of the first turbine vanes was a sharp edge orifice as shown in view A of figure III-D-1. The October Report, PWA FR-2156, reviewed cascade rig tests showing that this configuration was 1.5% to 4.0% low in total pressure readings.

By adding a chamfer to the edge of the orifice as shown in view B of figure III-D-1, the readings improved on one of the vanes but not on the other. Yaw probe traverses showed air angles from [illegible] es on one side of the center to 2 degrees on the other side. Interchanging vane positions showed that the air angle was the determining factor for a reduction in measurement error. The chamfer was an improvement, but it is still sensitive to the air approach angle.

A tube extension on the leading edge, as shown in view C of figure III-D-1, increased the air acceptance angle. Instrumentation laboratory tests indicated that the acceptance angle for 1% error was approximately doubled. Cascade rig tests at 2300°F and 107 psia showed pressure readings with zero to 1% error. A set of pressure instrumented vanes has been reoperated as shown in figure III-D-2 for engine testing.

4. Two-Dimensional Diffuser Rig

A two-dimensional diffuser rig was assembled and used for JTF17 primary combustor diffuser airflow studies. The rig, F-33449, is shown on D-32 stand in figure III-D-3. Tests were conducted on the experimental A-20 and the prototype A-21 diffusers as shown in figures III-D-4 and III-D-5, respectively. A summary of the test results is shown in table III-D-1.

Table III-D-1. Two-Dimensional Diffuser Tests

Diffuser Configuration	ΔP/P, %
Experimental - No struts	2.73
Prototype - No struts	2.49
Experimental - Round nose struts	2.25
Prototype - Struts	3.42
Experimental - Sharp leading edge struts	2.16
Experimental - Sharp struts - forward splitter extension	2.49

Testing is continuing on this diffuser rig to establish changes to the prototype diffuser strut and splitter design.

5. Fuel Nozzles

Post-test flow checks are in process for the Zone I duct heater nozzles and they are completed for the primary combustor nozzles from engine FX-161-5. The pretest and post-test flow checks do not indicate any flow shifts as shown by the comparison at three flow levels in figure III-D-6. These nozzles have 87.41 hours of JTF17 engine time and over 3 hours of operation with 370°F fuel temperature at the nozzle. Refer to engine section III-B (FX-161 test program). Figure III-D-7 shows the condition of details from a nozzle and support assembly after test. Nozzle tips and seals, from two assemblies that were instrumented to measure the fuel temperature at the inlet fittings, are shown in figure III-D-8.

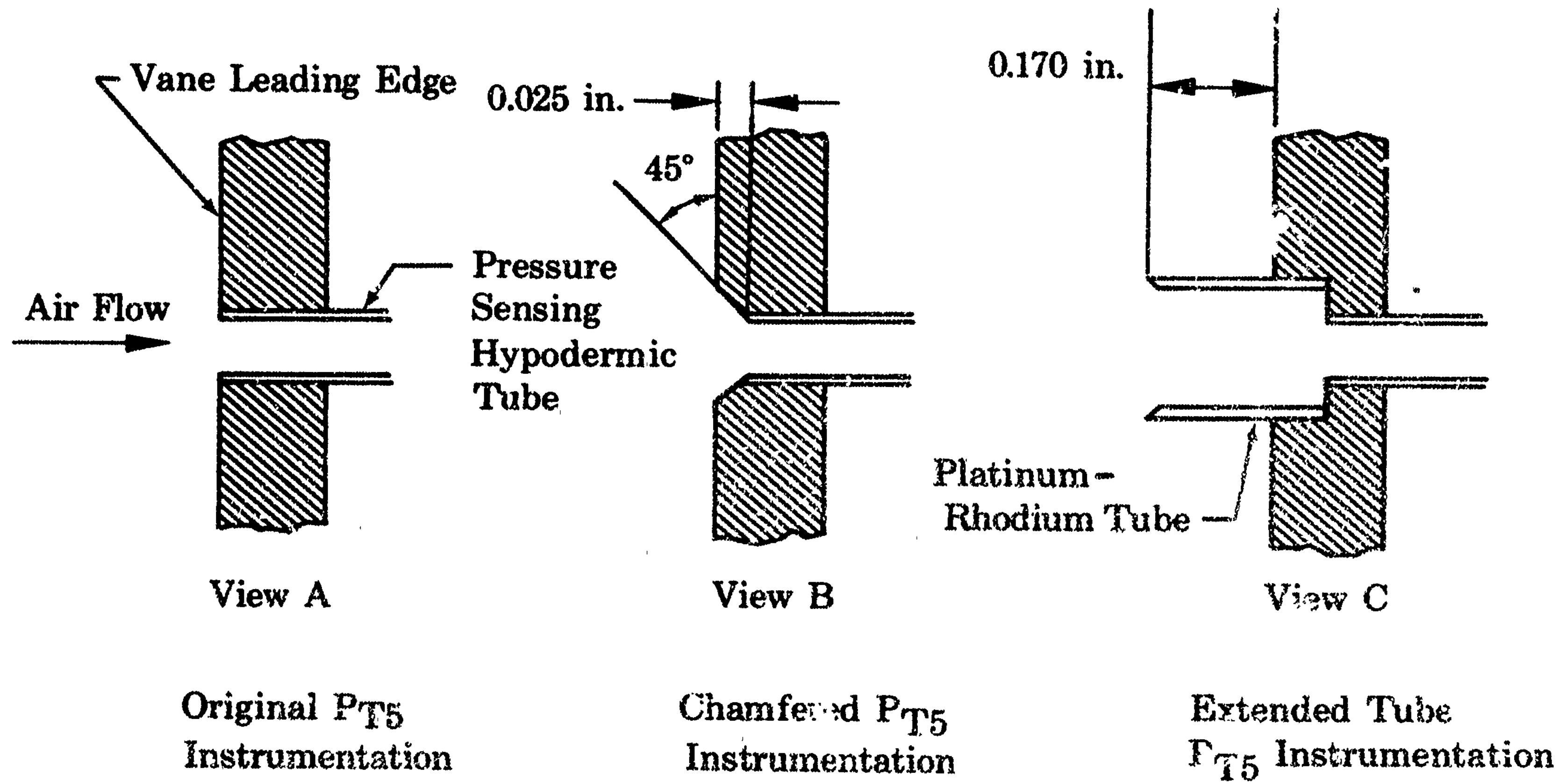


Figure III-D-1. Orifice Cross Sections of 1st-Stage Turbine Vane Pressure Instrumentation FD 19030

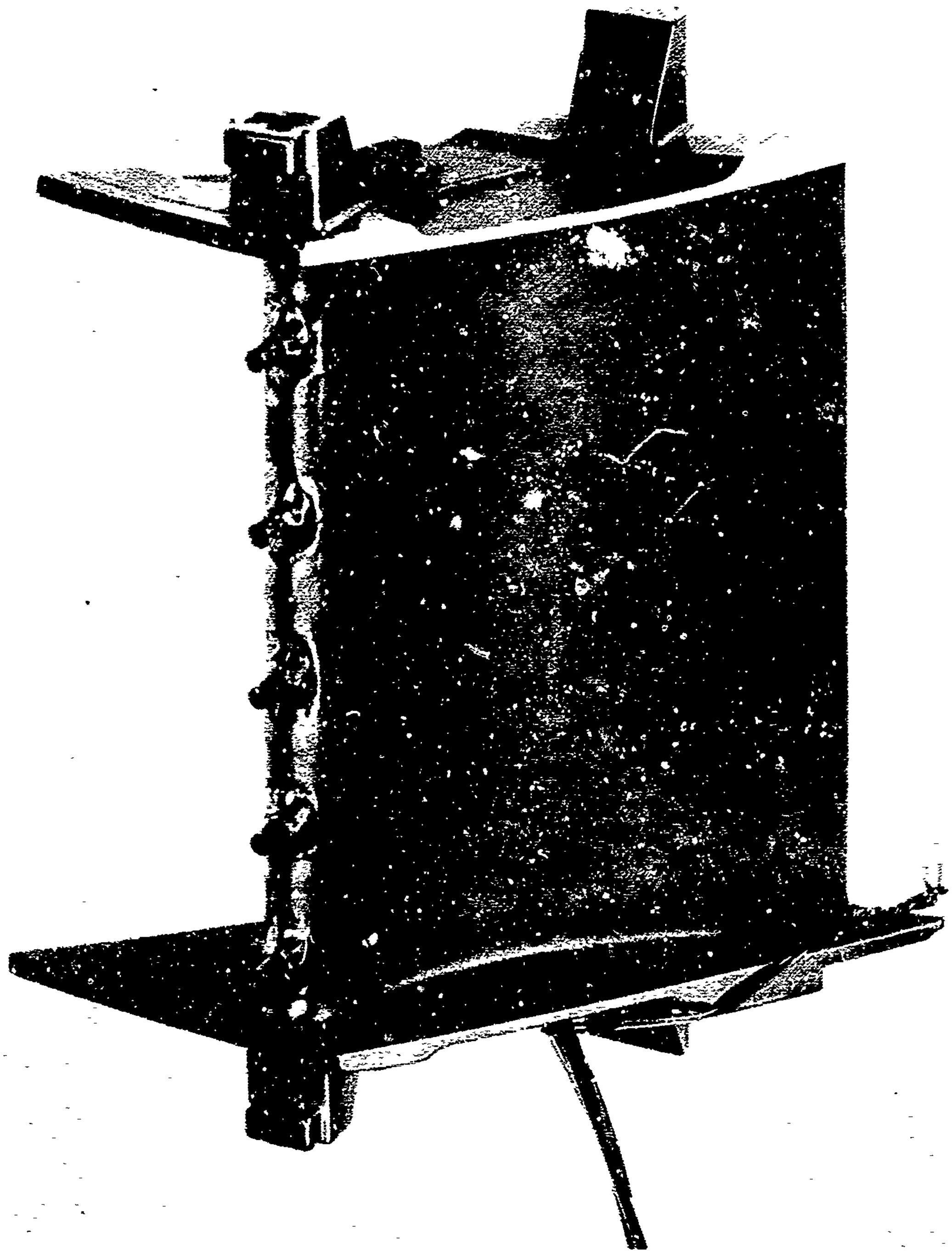


Figure III-D-2. 1st-Stage Turbine Vane With Pressure Instrumentation FE 65390

FE 64680

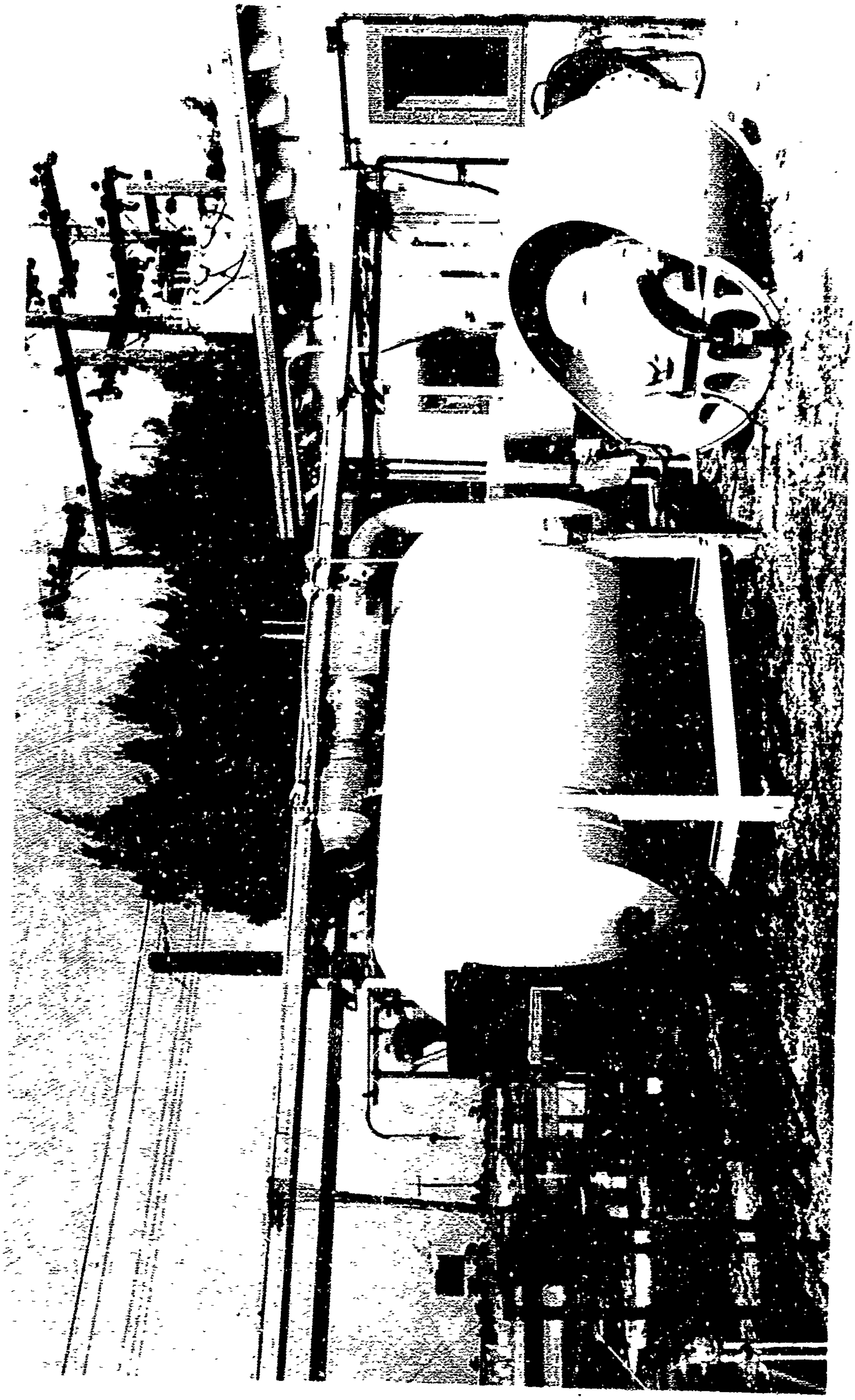
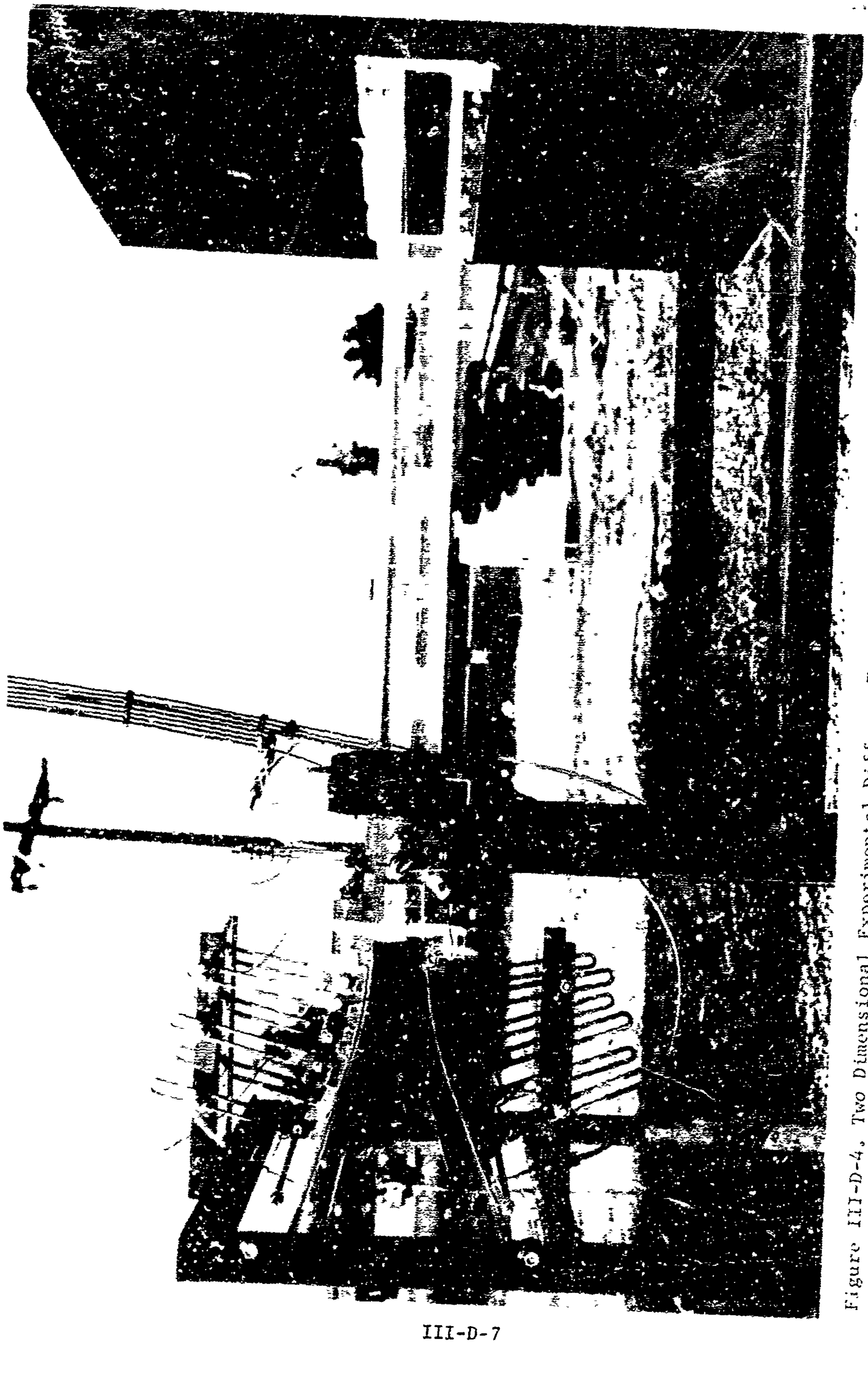


Figure III-D-3. Two Dimension Cold Airflow Diffuser Rig on D-32 Stand



FE 62571

Figure III-D-4. Two Dimensional Experimental Diffuser Test Rig

FC 13972

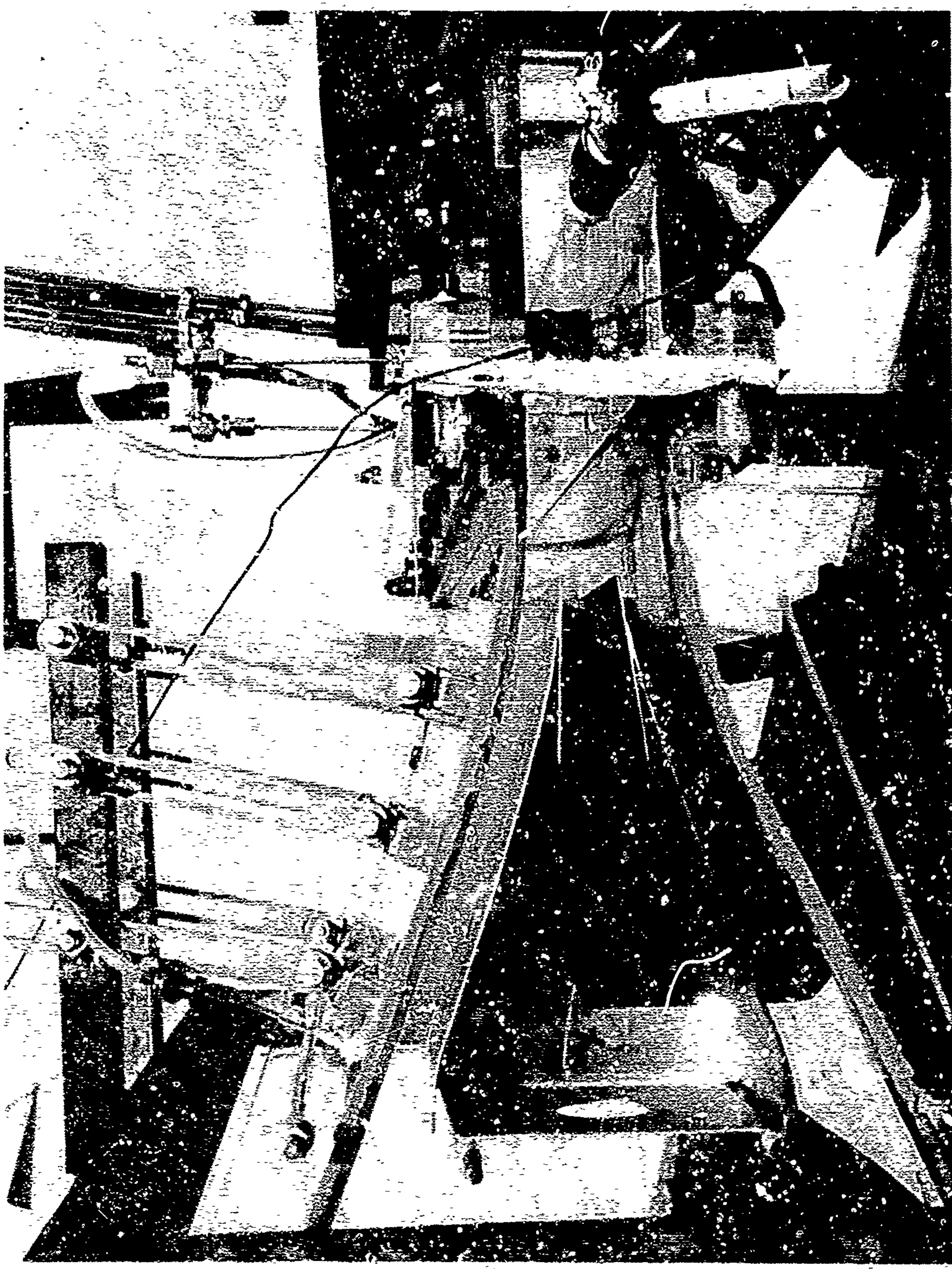


Figure III-D-5. Two Dimensional Prototype Diffuser Test : 3

DF 52509

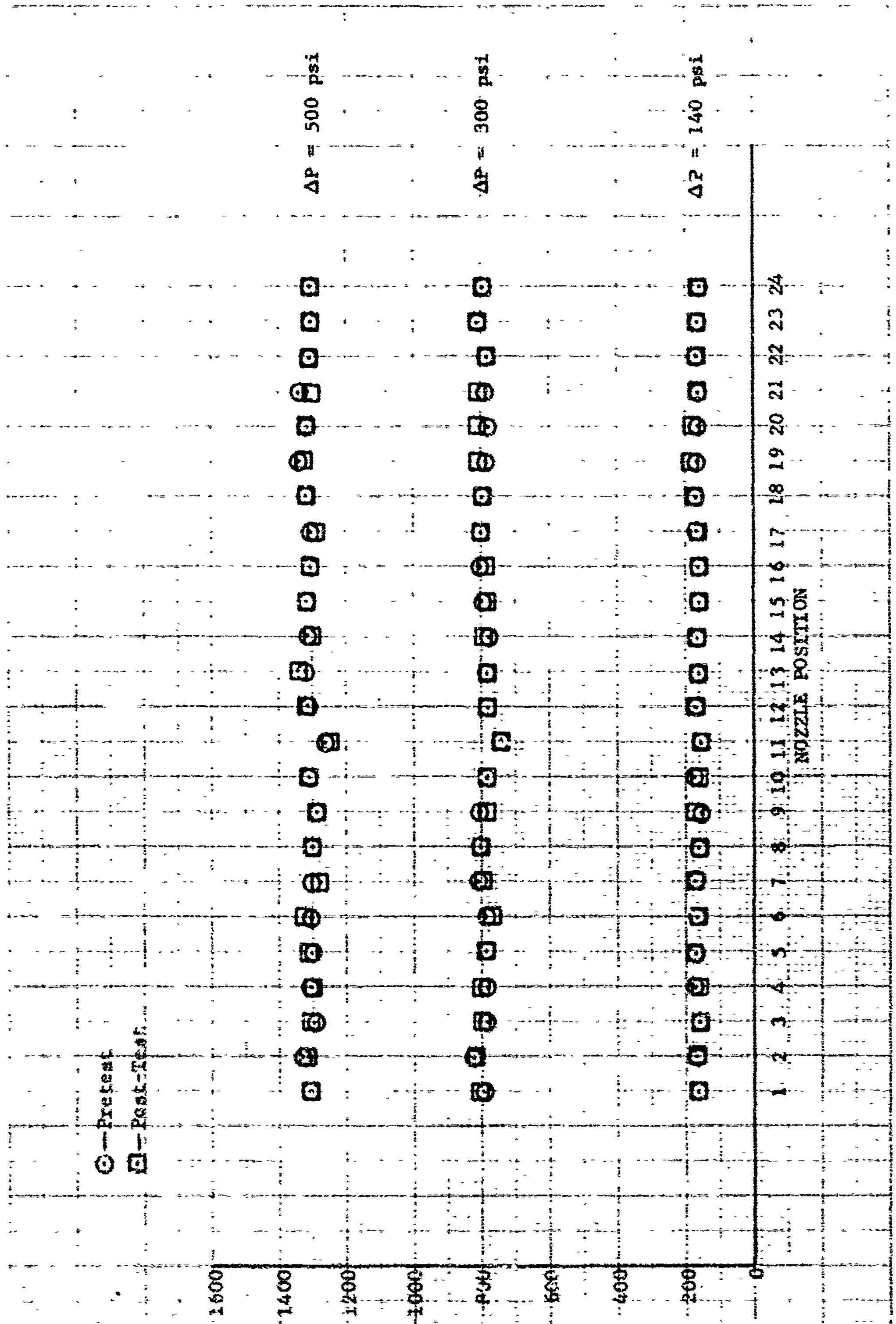


Figure III-D-6. Engine FX-161-5 Primary Combustor Nozzle Flow Test Results

FD 19029

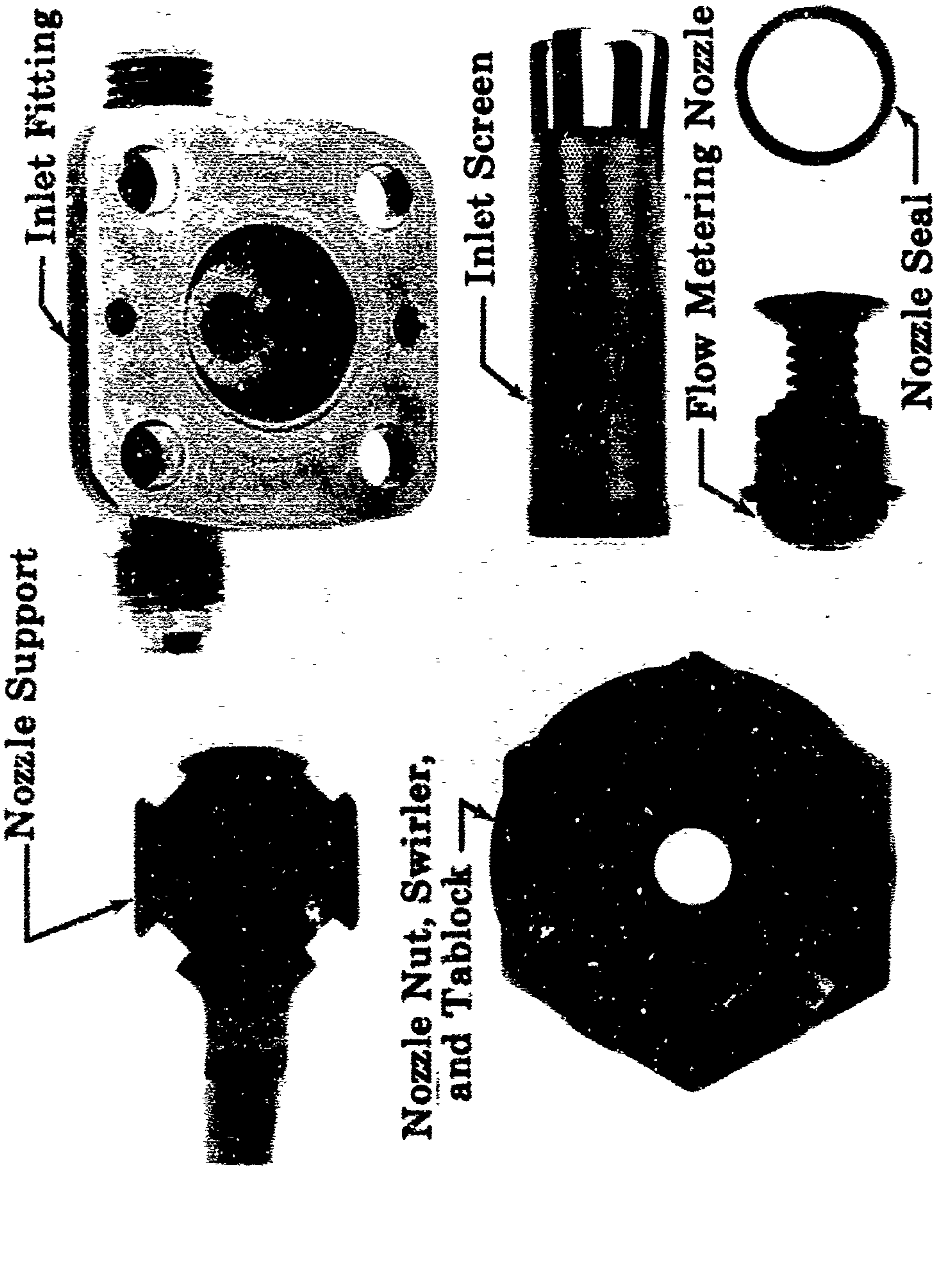


Figure III-D-7. Primary Combustor Fuel Nozzle and Support Details from Engine FX-161-5

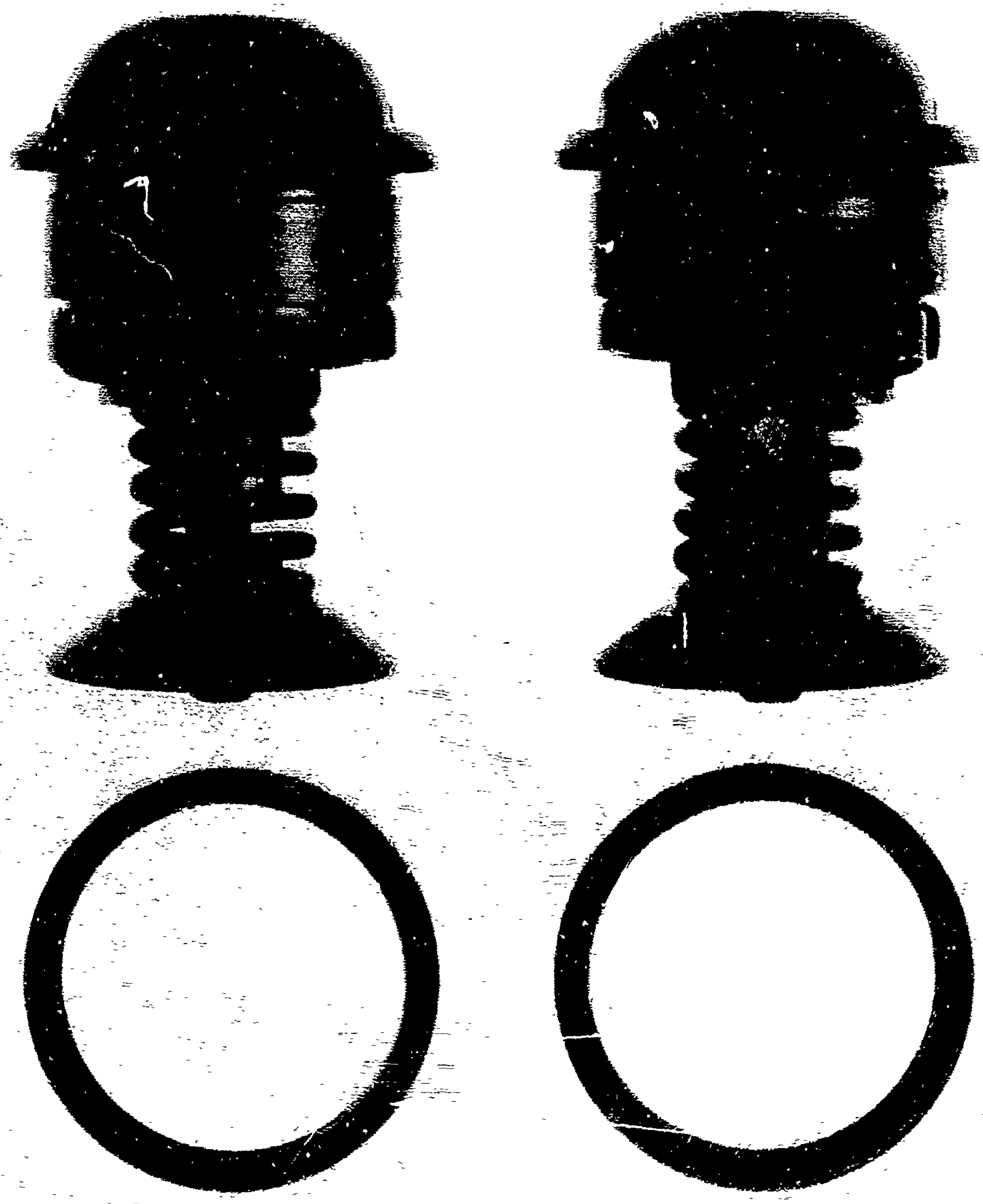


Figure III-D-8. Primary Combustor Fuel Nozzles and Seals from Engine FX-161-5 FE 65577

E. TURBINE

1. Thermodynamic Cascade Rig

	November	Phase II-C Total
Test Time, hours	23.91	445.95

The test results from the P&WA two-piece Thermal Skin$_{TM}$ 1st-stage blade (figure III-E-1) equaled the predicted values of the integral cast P&WA Thermal Skin$_{TM}$ blade (figure III-E-2). Modification of the removable internal airfoil to reduce thermal gradients across the blade is now in process and testing will continue next month. The P&WA two-piece Thermal Skin$_{TM}$ 1st-stage blade is considered to be a significant improvement over the integral cast P&WA Thermal Skin$_{TM}$ blade with respect to casting, fabrication, and inspection.

2. Related Technology

Testing of the impingement leading edge 1st-stage blade continued this month. The test specimen, which was fabricated using production tooling, incorporated 0.020-inch diameter leading edge impingement holes, trailing edge exit holes, and tip dump holes (figure III-E-3). Figure III-E-3 includes a metal temperature profile recorded at 2200°F TIT and 1100°F cooling air temperature. A change in the design has been initiated to reduce the high leading edge metal temperature and slightly increase the trailing edge metal temperature, increasing thermal fatigue life.

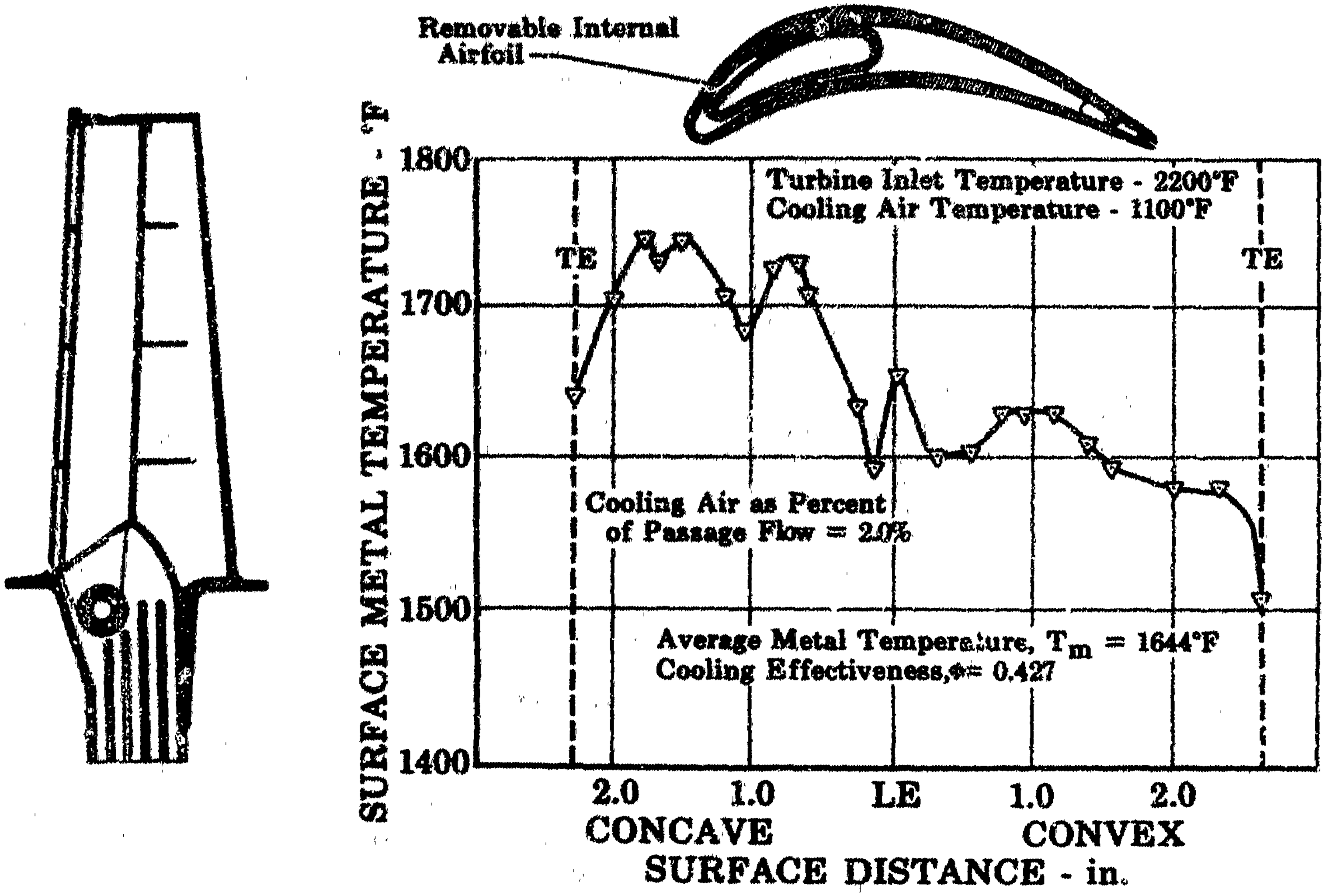
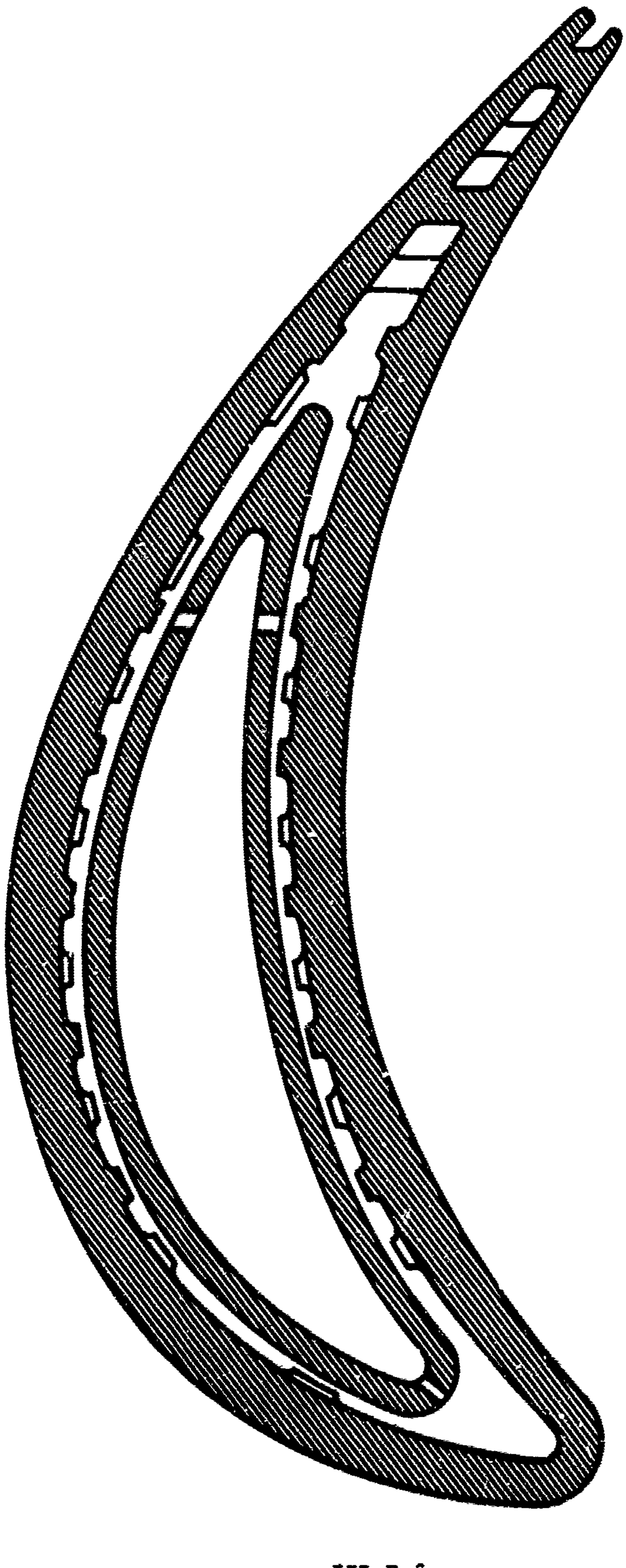


Figure III-E-1. JTF17 1st-Stage Turbine Blade - 2 Piece, P&WA Thermal Skin$_{TM}$

FD 19031



GS 1720

Figure III-E-2. JTF17A-20 1st-Stage 4-Wall Turbine Blade - 1 Piece, P&WA Thermal Skin$_{TM}$

FD 19032

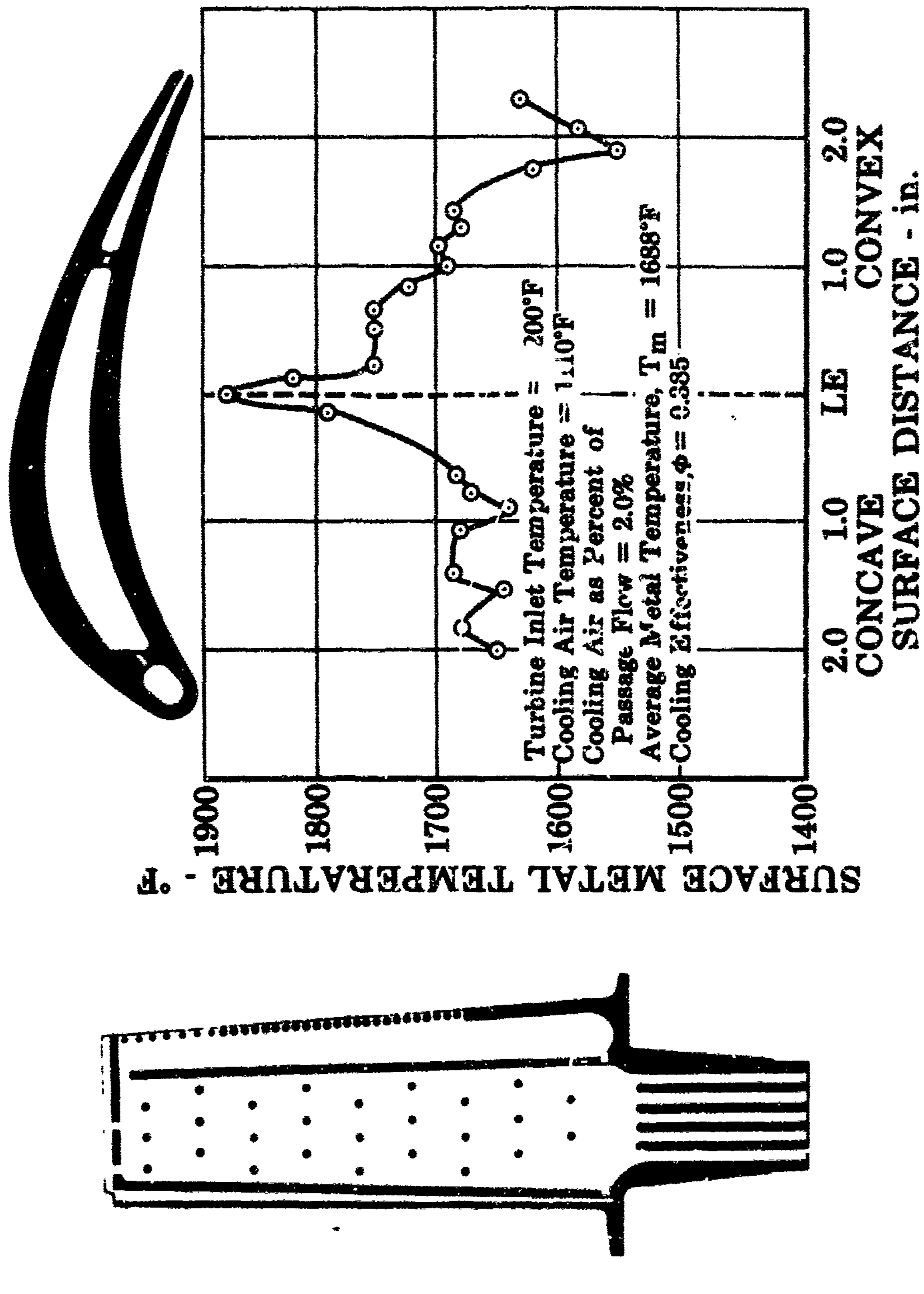


Figure III-E-3. 1st-Stage Turbine Blade - Impingement Cooled Leading Edge, Trailing Edge Exit, Tip Dump

F. AUGMENTOR

	November	Phase II-C Total
Full-Scale Rig Test Time:	0 hours	44.97 hours

The duct heater has now accumulated 26.20 hours of engine testing (with a maximum fuel/air ratio of 0.057) in addition to the 44.97 hours previously accumulated on the full-annular rig resulting in a total test time for Phase II-C of 71.17 hours.

Engine test results obtained to date compare closely to those of the full-annular rig. The duct heater was successfully operated at cruise conditions in engine FX-161 with the inlet distortion simulating the maximum level representative of the intended installation. The operating characteristics and performance of the duct heater were unaltered by the inlet distortion. All 67 attempts, at sea level and cruise conditions, to light the duct heater in JTF17 engines were successful. Smooth lights have been made with duct diffuser inlet Mach numbers as high as 0.9 (design maximum M = 0.56) and fuel/air ratios as low as 0.00157.

G. EXHAUST SYSTEM

The stat pressure tap cruise test program has been essentially completed. The objectives of the tests were to further investigate the supersonic performance potential of the JTF17 exhaust system and to compare measured pressure distributions with theoretical predictions. Complete data for these tests will be available by early December.

The scale model reverser test program to investigate reverser performance, targeting, and flow characteristics was initiated. Checkout of the flow visualization technique is complete, and photographs of the reverser flow patterns are being taken.

The Boeing wing model has been received from the vendor and is undergoing instrumentation prior to test (figure III-G-1). Approximately 50 pressure taps will be installed to establish the wing local flow field in the vicinity of the exhaust system. These tes s will be conducted in the United Aircraft Research Laboratory facilities in early December to gain additional exhaust system compatibility data.

Instrumentation of the first reverser-suppressor unit and fabrication of the second unit was completed during November. Engine testing is scheduled to be resumed during December. Figures III-G-2 and III-G-3 show the pressures and temperatures which will be recorded during these tests.

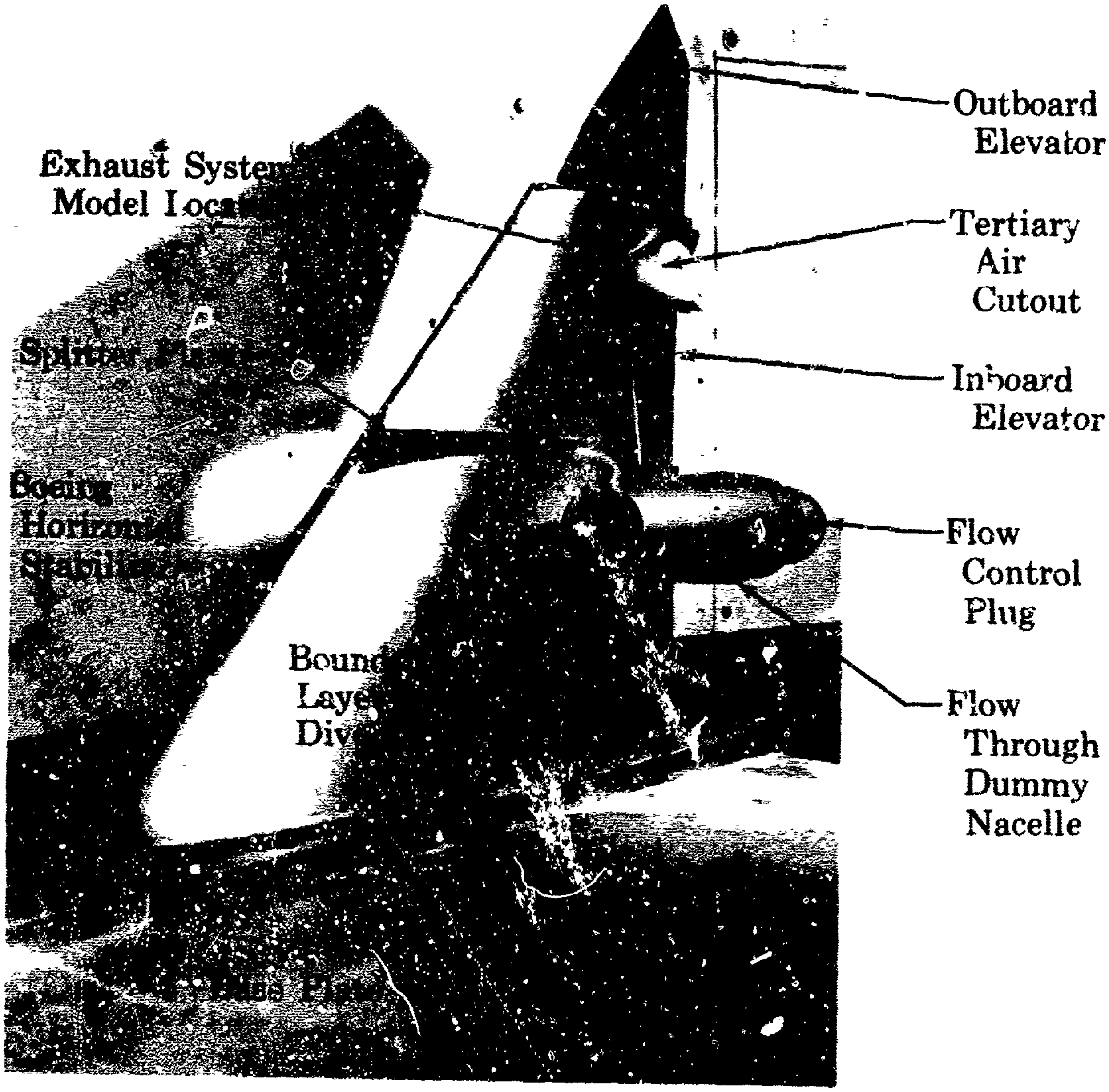


Figure III-G-1. Boeing Wing/Nacelle Model GS 4200

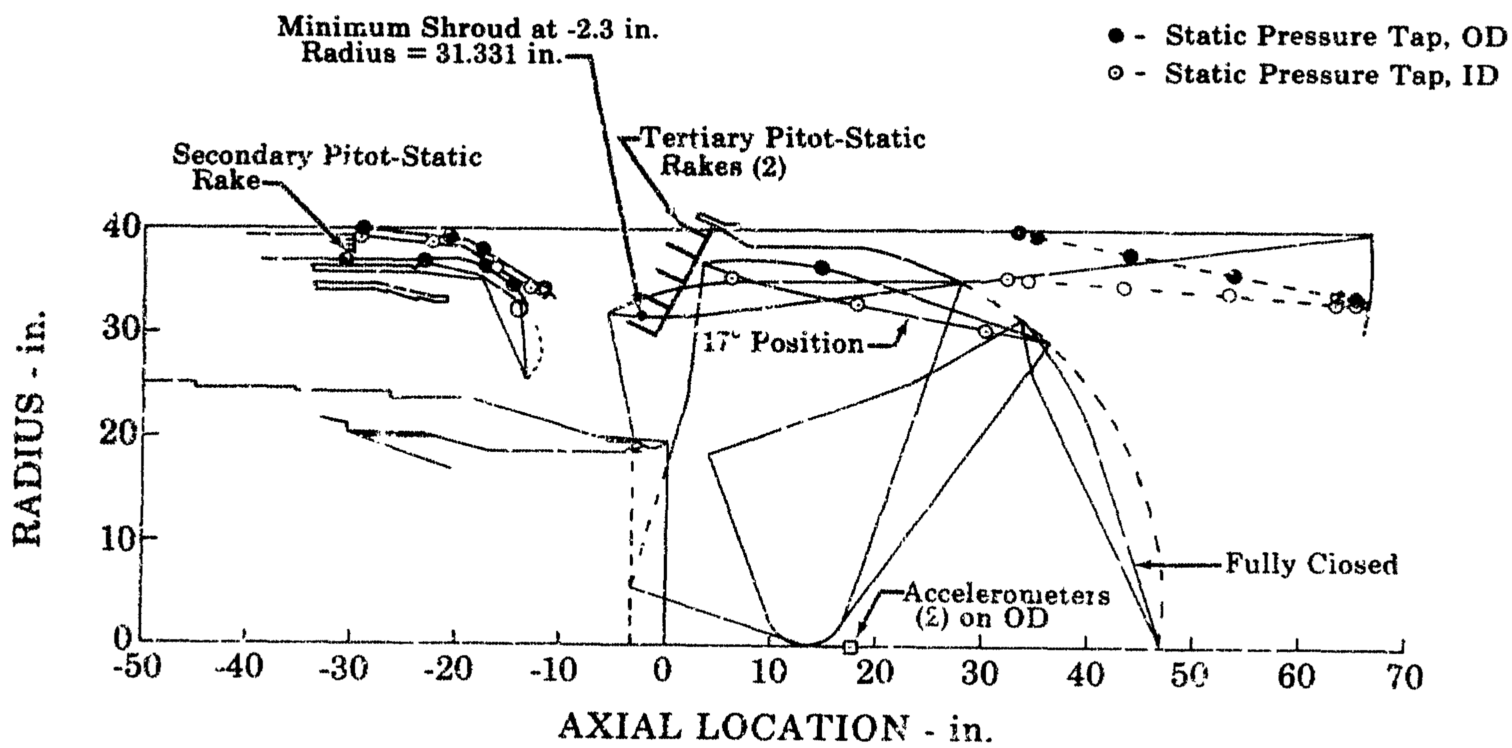


Figure III-G-? Engine FX-163 Instrumentation (Pressure Taps) for Reverser-Suppressor FD 18989

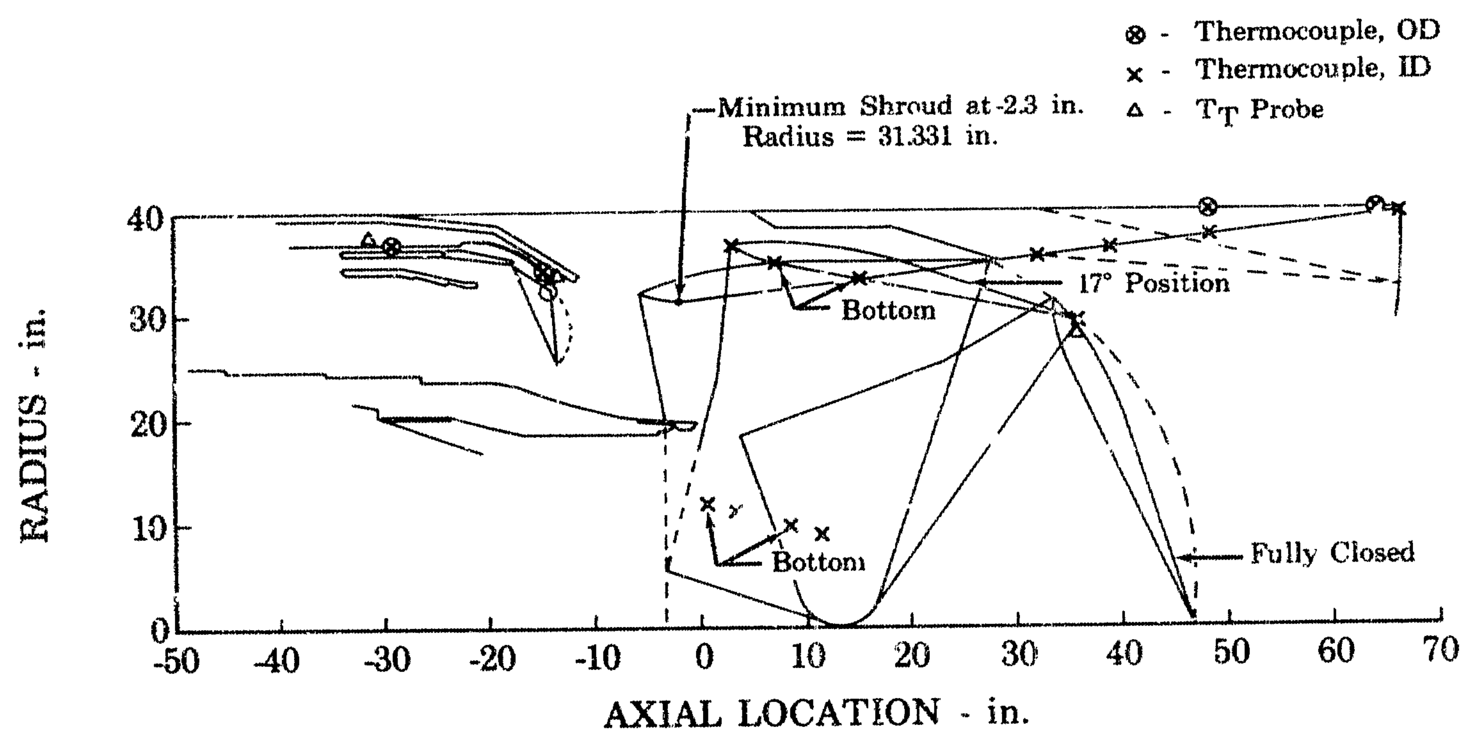


Figure III-G-3. Engine FX-163 Instrumentation (Thermocouple) for Reverser-Suppressor

FD 18990

H. CONTROLS

1. Initial Experimental JTF17A-20 Control System

a. Duct Airflow Computer (Breadboard)

The Hamilton Standard S/N 1 breadboard computer unit was bench tested at FRDC to investigate the overall accuracy of the unit. The data are being evaluated.

b. Duct Fuel Controls

(1) Modified JFC-51 Duct Fuel Controls

The modified JFC-51 control continued to perform satisfactorily on engine FX-161. The second control is engine ready.

(2) AA-M1 Duct Heater Fuel and Nozzle Area Control

A T_{T2} bias cam, a revised fuel flow schedule cam, and a reduced gain integrator cam have been installed in AA-M1 Control S/N D07C001. The T_{T2} bias cam will allow the fuel schedule rate to be varied by mechanical trimming of the T_{T2} servo. This bias feature will be used to match the fuel flow and exhaust nozzle area schedules to provide optimum control system operation as evidenced by minimum integrator piston motion. A linear potentiometer has been installed inside the control to produce a remote indication of integrator piston travel. This control is undergoing final bench calibration at P&WA.

AA-M1 Control (S/N D07C002) was partially disassembled at P&WA and the integrator cam was sent to Bendix for rework to reduce the integrator gain. Bendix is manufacturing a T_{T2} bias cam and a revised fuel flow cam for installation into this control. A linear potentiometer as described in the preceding paragraph, is also being incorporated during this control modification.

AA-M1 Control (S/N D07C003) was shipped from Bendix on 17 November. The schedules in this control are the same as in S/N D07C001, described above.

c. Ignition

The JT12, 4-joule, low tension, ignition system with the JTF17 type shunted gap igniters has ignited the gas generator 132 times and the duct heater 67 times on JTF17 experimental engines. Nineteen of the duct lights were altitude lights.

d. Quick-Fill

Bendix has completed a layout and is producing detail drawings for the prototype quick-fill kit to be used with the AA-M1 duct heater controls.

e. Duct Fuel Pump

A bench test was conducted that demonstrated the maximum flow capability of 86,000 pph using the duct fuel pump that is assigned to engine FX-163-2.

2. Prototype JTF17 Engine Control

a. Conceptual Design

Both control vendors have supplied schematics which satisfy the requirements of the noise abatement mode. Noise abatement is achieved by allowing the duct heater to be operated below maximum gas generator power. The noise abatement mode is selected by placing the shutoff lever in the noise abatement position.

Operation of the system would be as follows:

1. Just prior to or during the takeoff roll the shutoff lever would be placed in the noise abatement position.
2. Takeoff would be accomplished at part or maximum augmented power setting. After the takeoff has been completed, the engine power would be decreased to the part gas generator power setting necessary to maintain the desired rate of climb or loiter altitude. The duct heater will remain on and will supply some augmentation which is matched for minimum noise level for the thrust level selected.

3. Acceleration out of noise abatement into normal augmentation is accomplished by power lever motion the same as before addition of the noise abatement mode.

4. Noise abatement can be shut off by moving the shutoff lever into the normal run position. Noise abatement is also shut off when the power lever is moved below the minimum noise abatement power lever position.

b. Digital Electronic Airflow Computer

Both vendors being considered for the unitized fuel and area control have submitted proposals for an electronic module that would control airflow and certain other functions as an alternative approach. The vendors are continuing design studies to ascertain that when the module is mounted on the unitized fuel and area control, the allowable engine dimensions will not be exceeded. Evaluation of proposals is continuing.

c. EPR Control

Evaluation of the proposal for the optional EPR controls is continuing.

d. FRDC Computer Studies of the JTF17 Control System

Dynamic simulations of the proposed JTF17 noise abatement system were conducted on the digital computer. Results of these studies are presented in figures III-H-2 through III-H-4.

The schedule used in these simulations is a 0.005 duct heater fuel/air ratio at minimum thrust setting with a linear decrease in fuel/air ratio to 0.002 at maximum gas generator power.

Duct heater fuel/air ratios are limited to the noise abatement level until the high rotor speed exceeds 80% of maximum during a rapid power lever transient.

Figure III-H-1 illustrates a transient into minimum noise abatement and from minimum noise abatement to maximum augmentation.

The operating point was set just below 80% N_2 when noise abatement was selected. The duct heater lit at a 0.002 fuel/air ratio and increased to 0.005. Three seconds after noise abatement was selected, the PLA was

advanced to maximum; three seconds after the PLA was moved, the engine was producing maximum thrust.

Figure III-H-2 shows engine response to a reduction in power from maximum augmentation to minimum noise abatement. The transient required 1.75 seconds to reach a steady-state speed from the time of the PLA change.

Figure III-H-3 illustrates engine response to noise abatement when it is turned on and off. The cutoff of noise abatement is shown as a step function. During the development program, the cutoff may be revised to provide a time rate decrease of thrust.

A dynamic simulation of the latest Boeing inlet was received and is being integrated into the system. It will be used to check engine/inlet compatibility and to ensure optimum operation throughout the operational range.

e. Prototype Duct Heater Fuel Pump

Hamilton Standard has incorporated the oil cooler bypass valve as an integral part of the duct heater fuel pump. Revised installation drawings showing this feature have been received at P&WA.

3. Failure Mode and Effect Analysis (FMEA)

The control system FMEA was completed for Phase II-C with the issuance of the reliability block diagram as reported in last month's progress report. Therefore, this item will no longer be included in this report.

4. Advance Control System Program (Related Technology) - Exhaust Gas Temperature (EGT) Control for the J58 Engine

Thirteen production models of the electronic (analog) units have been delivered, and flight suitability tests have been completed. Preparations for flight testing of these systems is underway. Engine tests of the experimental digital breadboard version of this equipment are continuing.

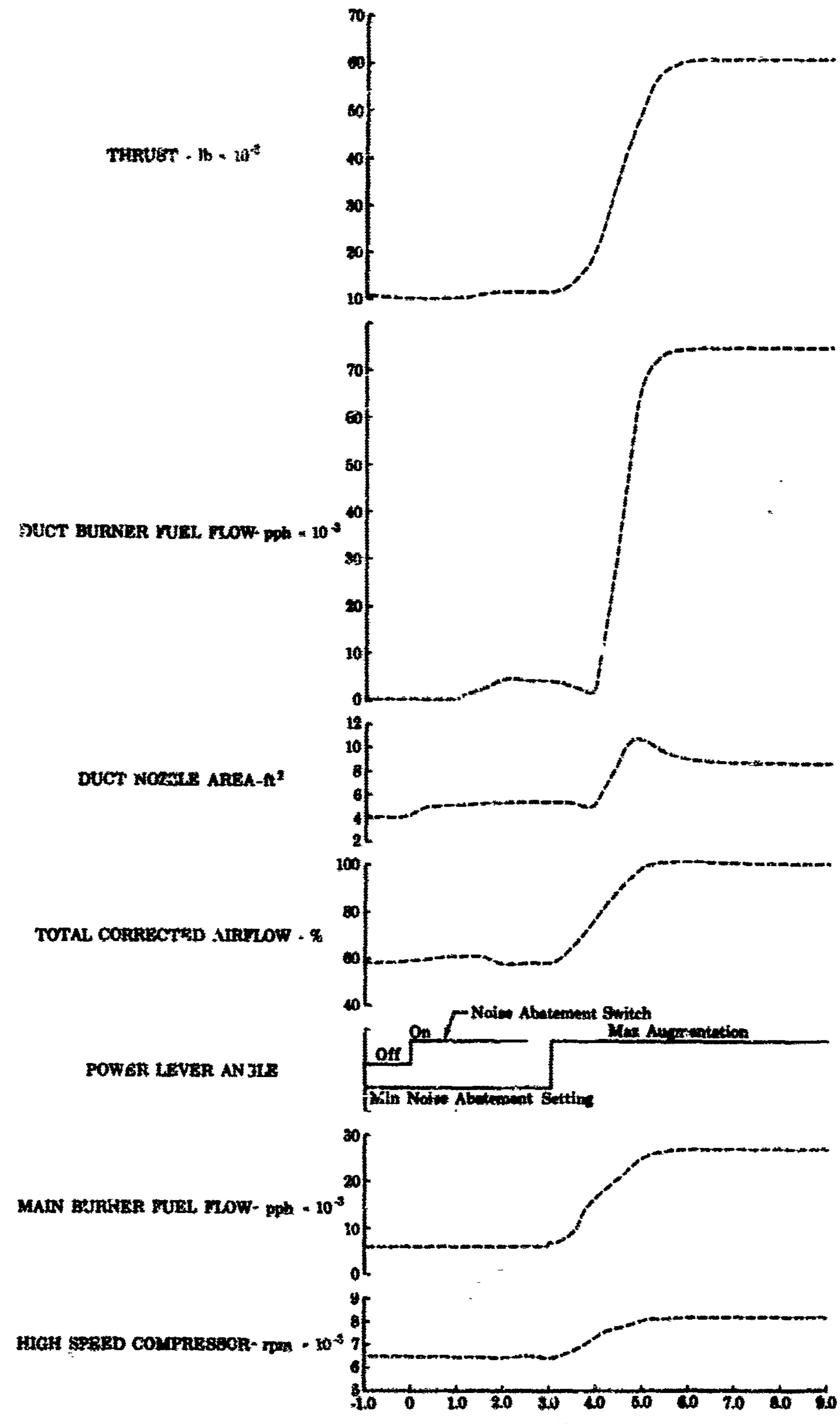


Figure III-H-1. JTF17A-21 Response to PLA Modulation FD 19041 from Minimum Noise Abatement to Maximum Augmentation at Sea Level

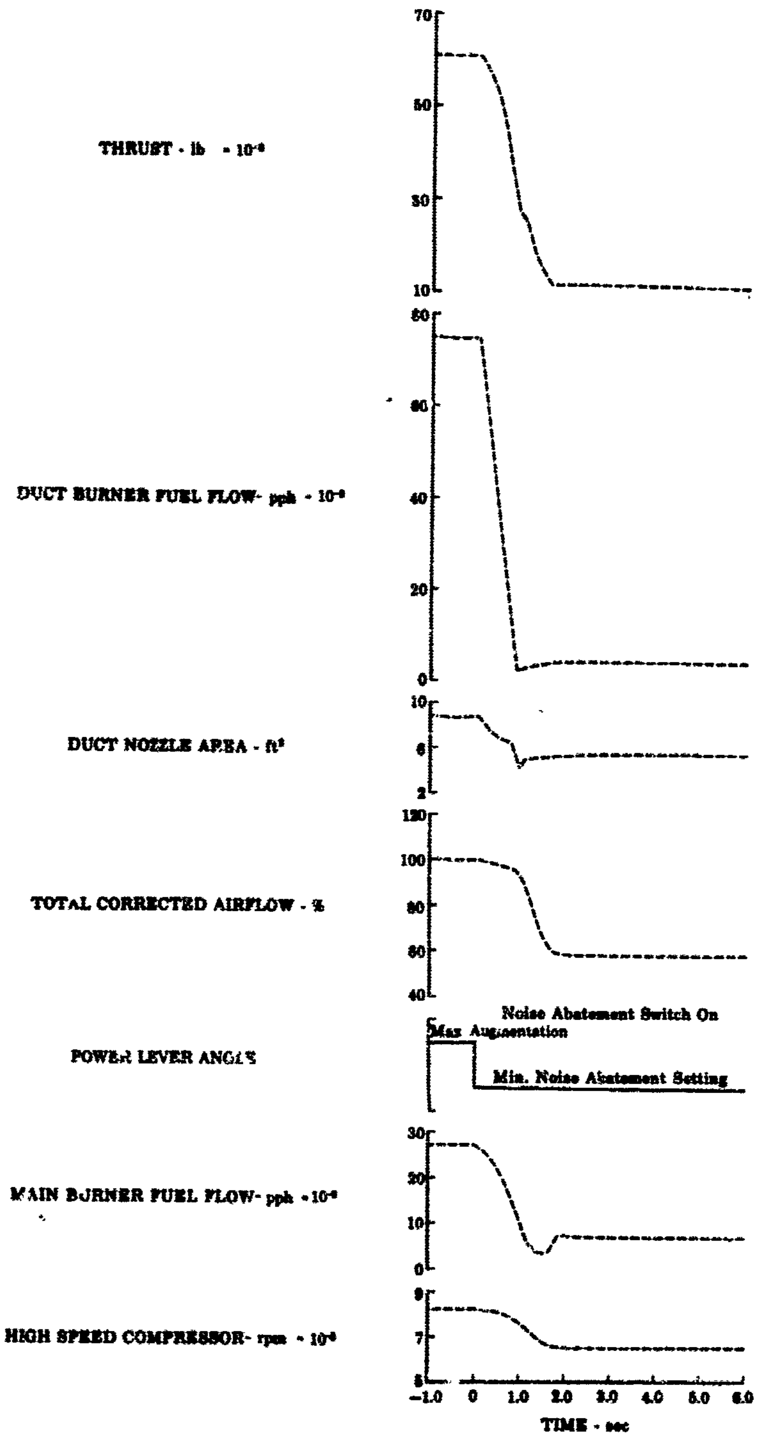


Figure III-H-2. JTF17A-21 Response to PLA Modulation FD 19042 from Maximum Augmented to Minimum Noise Abatement

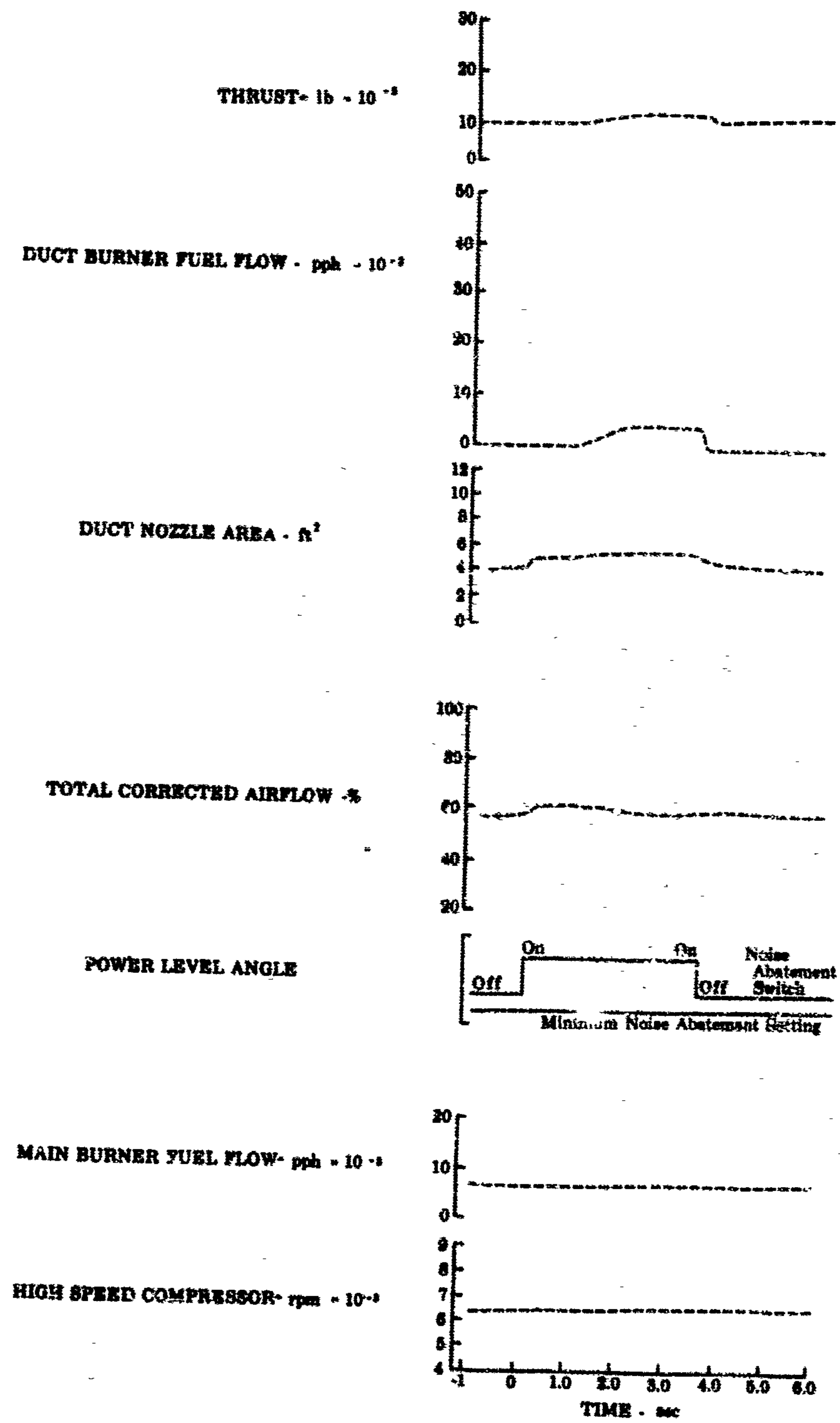


Figure III-H-3. JTF17A-21 Response to Noise Abatement Mode Selector Being Moved Into and Out of Noise Abatement

FD 19043

I. BEARINGS AND SEALS

No rig development testing has been accomplished on bearings and seals during this report period.

J. FUELS AND LUBRICANTS

1. Fuels

Fuel coker tests on aviation kerosene have continued to confirm that the fuel used in the experimental JTF17 engines is meeting the purchase specification requirements. This continued monitoring of the fuel deliveries disclosed a problem with one of the fuel suppliers storage tanks and prevented the delivery of unacceptable quality fuel.

Testing has been accomplished in the JTF17 engine at cruise conditions with fuel temperatures up to 370°F. Refer to engine section III-B (FX-161 Test Program). Refer to section III-D for additional information on the condition of the fuel nozzles.

2. Lubricants

Laboratory tests were continued on candidate lubricants to ensure conformance to specification requirements. Testing has been accomplished in the JTF17 engine at cruise conditions with the lubricant temperatures up to 360°F. Refer to engine section III-B (FX-161 Test Program).

K. INLET SYSTEM COMPATIBILITY

1. Inlet Distortion

Distortion tests were conducted on the 0.6-scale fan rig and the JTF17A-20 engine. In both cases the inlet total pressure distortion was generated with screens located at least one duct diameter ahead of the fan in order to minimize the influence of the screen on the fan inlet static pressure profile.

a. 0.6-Scale Fan Rig

These tests were performed to determine the effect of distortion on the fan surge line at cruise and to document the capability of the fan to attenuate the distortion.

The surge line on the engine side (reference figure III-B-5) of the fan was substantially unaffected by the inlet distortion. On the duct side a slight loss (3%) in surge margin was measured. The distortion introduced to the fan exceeded both the Boeing and Lockheed cruise distortion. The values of the distortion index, K_{d2}, are tabulated below:

Cruise Distortion Simulation

	Test	Boeing	Lockheed
K_{d2}	466	153 (Critical)	405
		306 (2% Supercritical)	

The pressure gradients created at the fan discharge by the inlet distortion are presented in figure III-K-1 together with the inlet distortion pattern. The excellent capacity of the fan to attenuate distortion before entering the duct heater is ev: at since the fan discharge pressure is little affected by the distortion. Small differences (± 1%) are noted in only scattered regions comprising a minor portion of the fan duct discharge area. On the engine side (entering the compressor) the attenuation is also excellent although not as complete as that on the duct side. As shown, the regions in which the pressure is more than ± 2% different from the average are significantly reduced in size upon leaving the fan. These fan attenuation data show that the high pressure compressor will be required to tolerate only a fraction of the inlet distortion.

The attenuation of the circumferential component of the distortion is depicted in figures III-K-2 and III-K-3. These data show the pressure distributions entering and leaving the fan on the mean streamline for the engine and duct streams, respectively. The difference between the maximum and minimum pressures at the fan discharge is approximately 3% of average on the engine side and 2% on the duct side. Entering the fan, this difference is approximately 8%. Good attenuation of the average radial component of distortion is also attained (figure III-K-4). The change in the average radial discharge profile due to the inlet distortion reaches a maximum of about 1/2%, or 1/3 of the radial component of the inlet distortion.

b. JTF17 Engine FX-161-5

The engine was run at simulated cruise conditions in an altitude test cell with distortion generated by inlet duct screens. Normal engine operation was attained at a distortion level representative of the intended installations. (Reference figure III-B-3.) As anticipated on he basis of the fan rig tests, the engine did not encounter stall or surge and no measurable effect on engine performance was noted. These data are detailed in engine performance section III-B-3.

The attenuation of the distortion on the duct side of the fan was found to be substantially complete as in the case of the fan rig tests. The distortion did not alter any discharge pressure by more than 2%.

The influence of the high pressure compressor on distortion attenuation was measured for the first time during these tests. At the compressor discharge the largest incremental pressure attributable to the inlet distortion slightly exceeded 2% over a very small region. The effect of the distortion on turbine inlet temperature was found to be negligible.

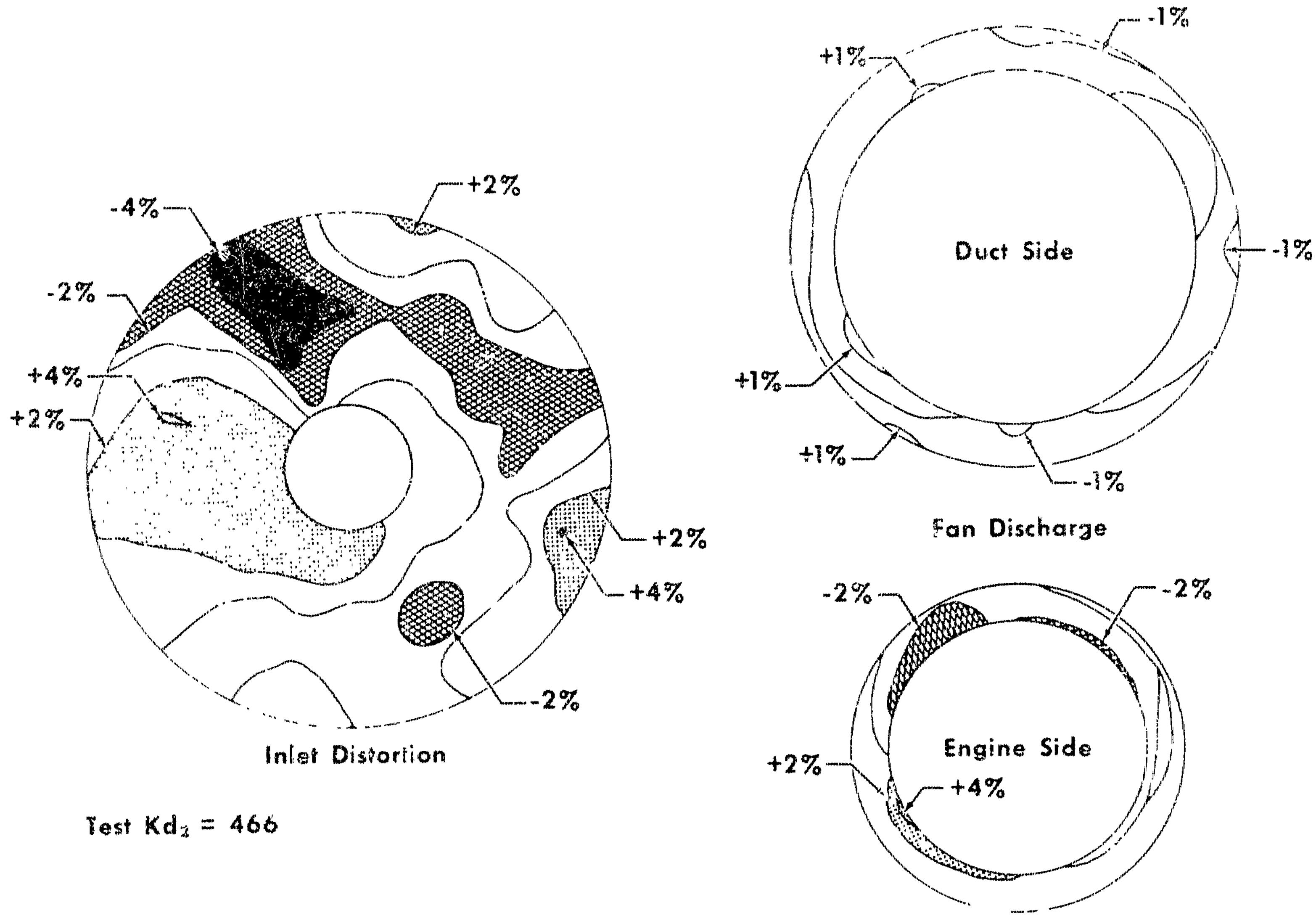
2. Engine/Inlet Compatibility

A digital dynamic simulation of the Boeing inlet was received and incorporated into the JTF17 engine simulation. Figures III-K-5 through III-K-7 demonstrate the stability of the system at cruise for the following failure transients: duct heater light, duct heater blowout, and primary combustor blowout. A failure analysis is proceeding with the Boeing inlet/JTF17 simulation.

Lockheed is preparing an updated inlet simulation for the engine/inlet compatibility study. The estimated completion date is 30 November.

IBM system 360 JTF17 simulations are being prepared for both airframe manufacturers. Boeing has requested a formulation of the JTF17 engine simulation to enable them to begin a hybrid simulation of the propulsion system. A tape of the Fortran language statements is being prepared for transmittal to Boeing.

A digital dynamic simulation of the JTF17 engine and control for transmittal to the Air Force Aero-Propulsion Laboratory is being prepared.



GS 4167

Figure III-K-1. JTF17 Fan Distortion Test - Cruise Distortion Simulation

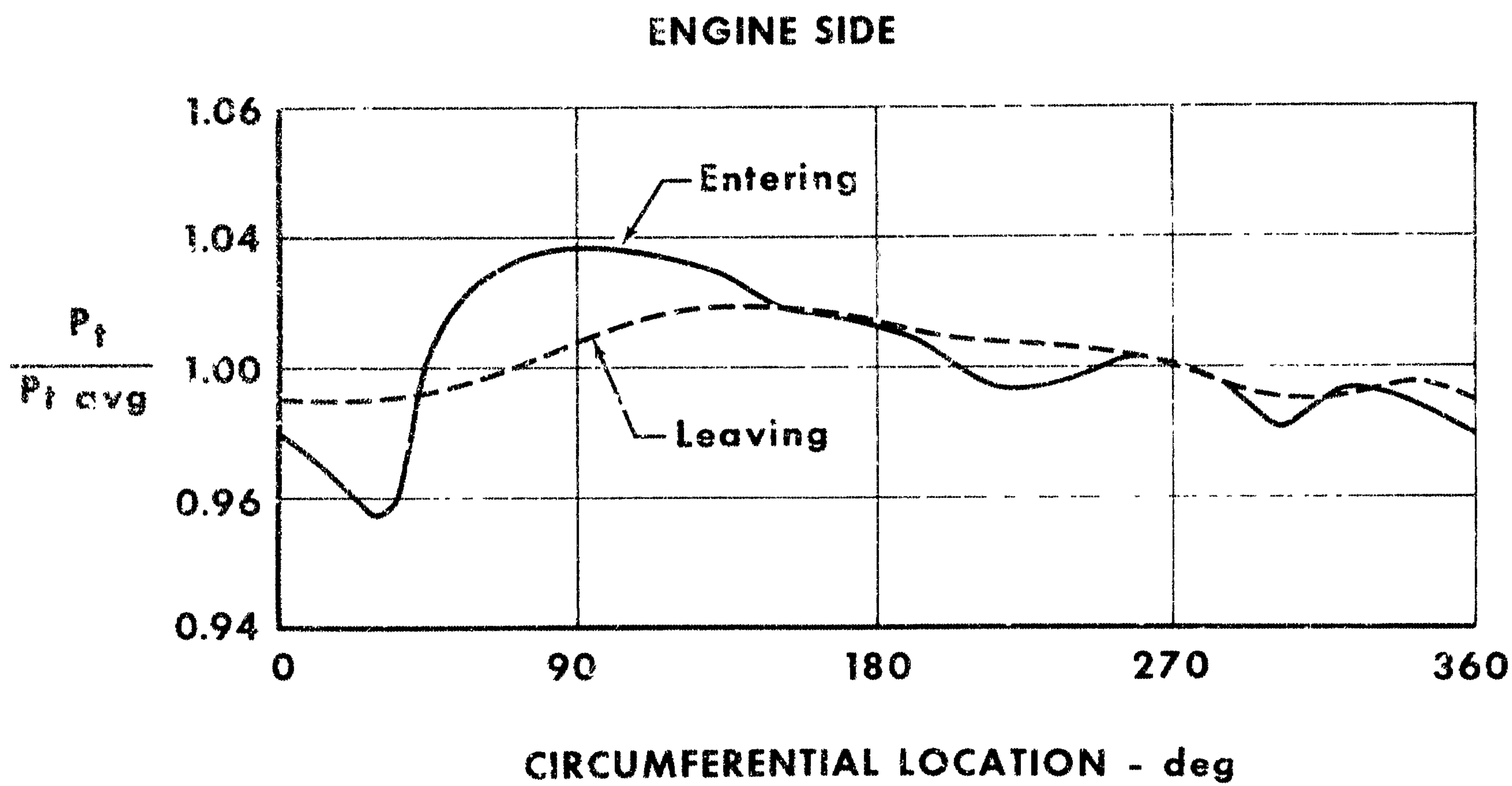
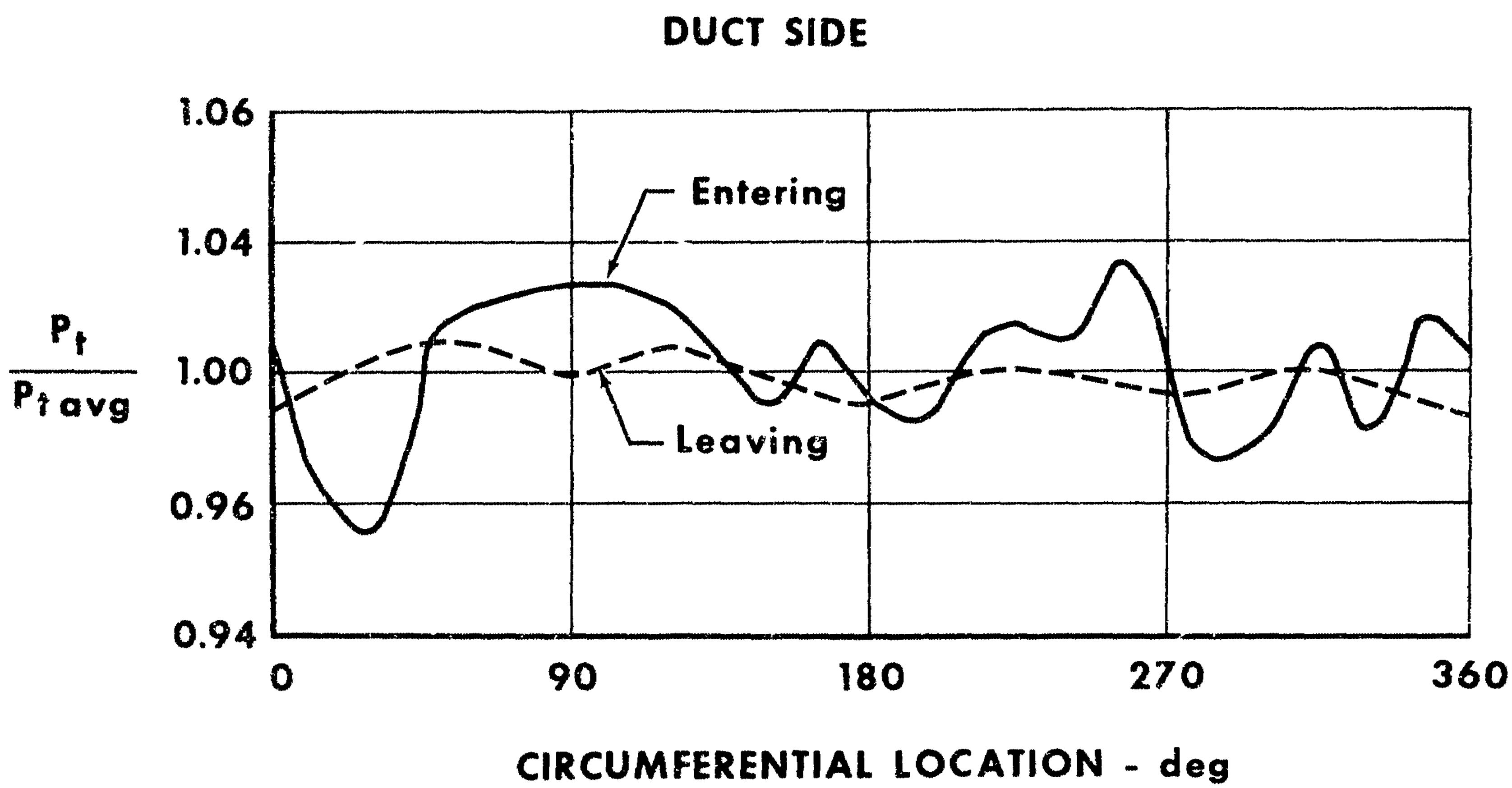


Figure III-K-2. JTF17 Fan Attenuation of Circumferential Total Pressure Distortion

GS 4169



GS 4168

Figure III-K-3. JTF17 Fan Attenuation of Circumferential Total Pressure Distortion

GS 4162

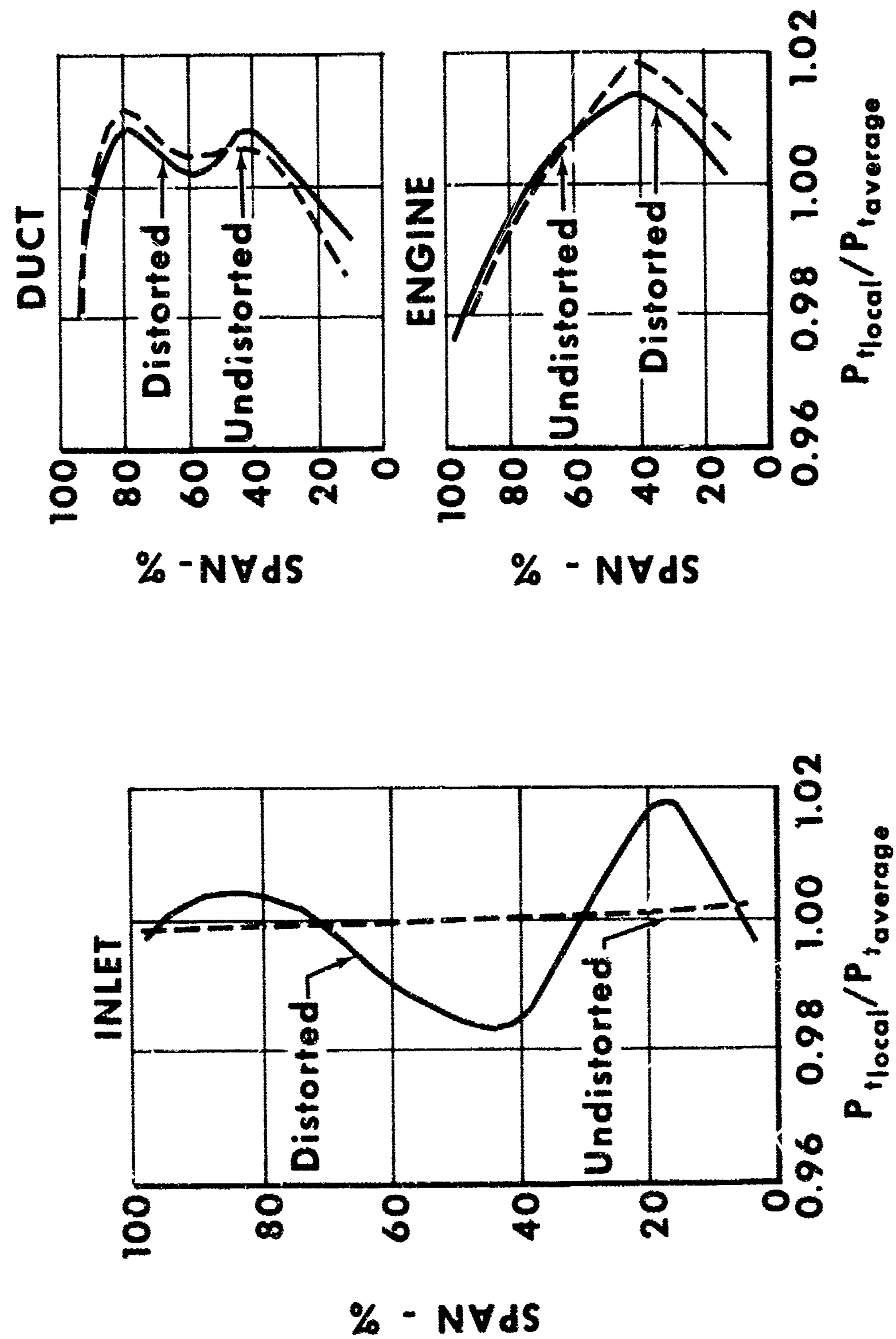


Figure III-K-4. JTF17 Fan Attenuation of Radial Total Pressure Distortion

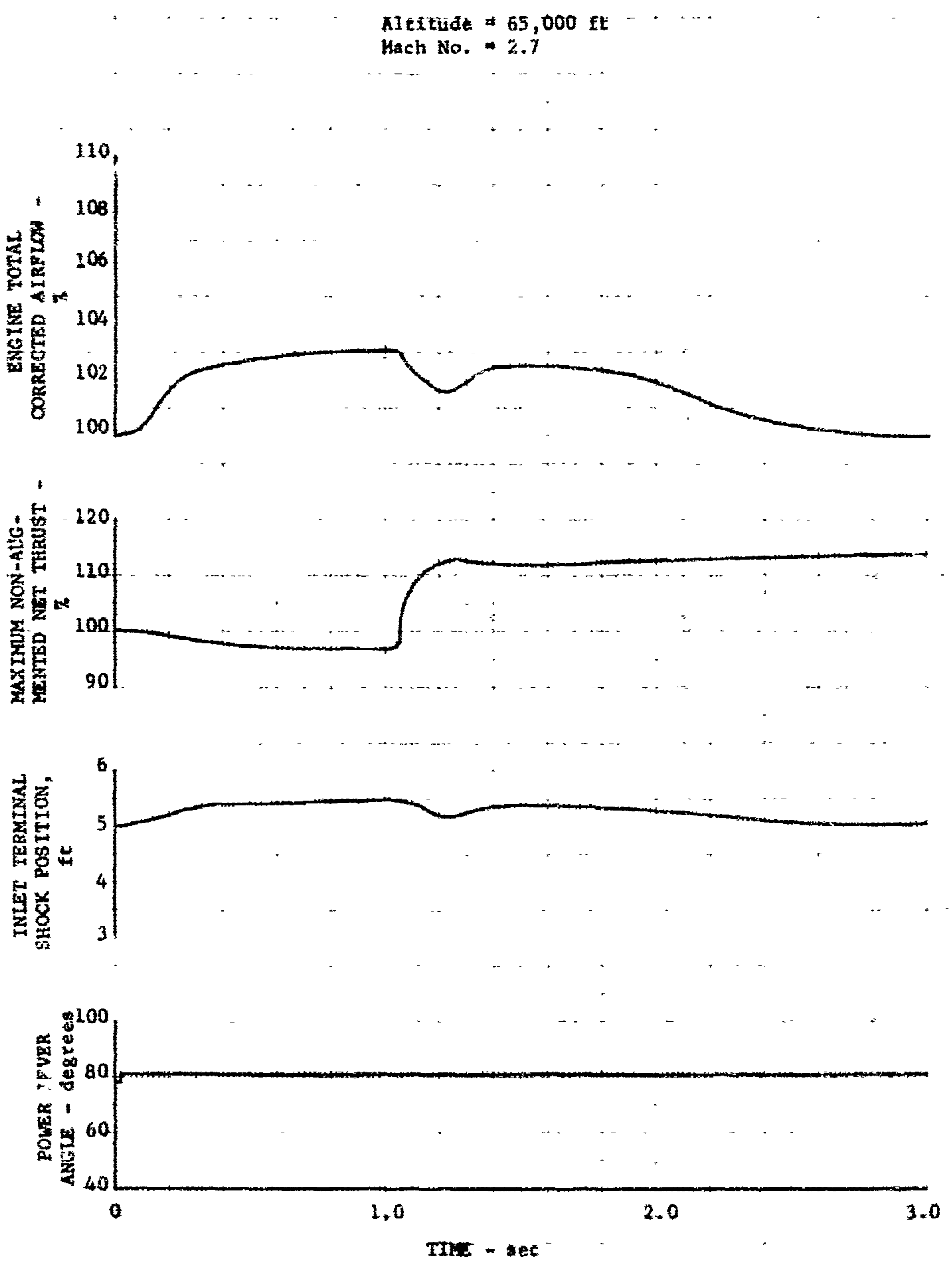


Figure III-K-5. JTF17 Estimated Dynamic Performance, Duct Heater Light DF 52504

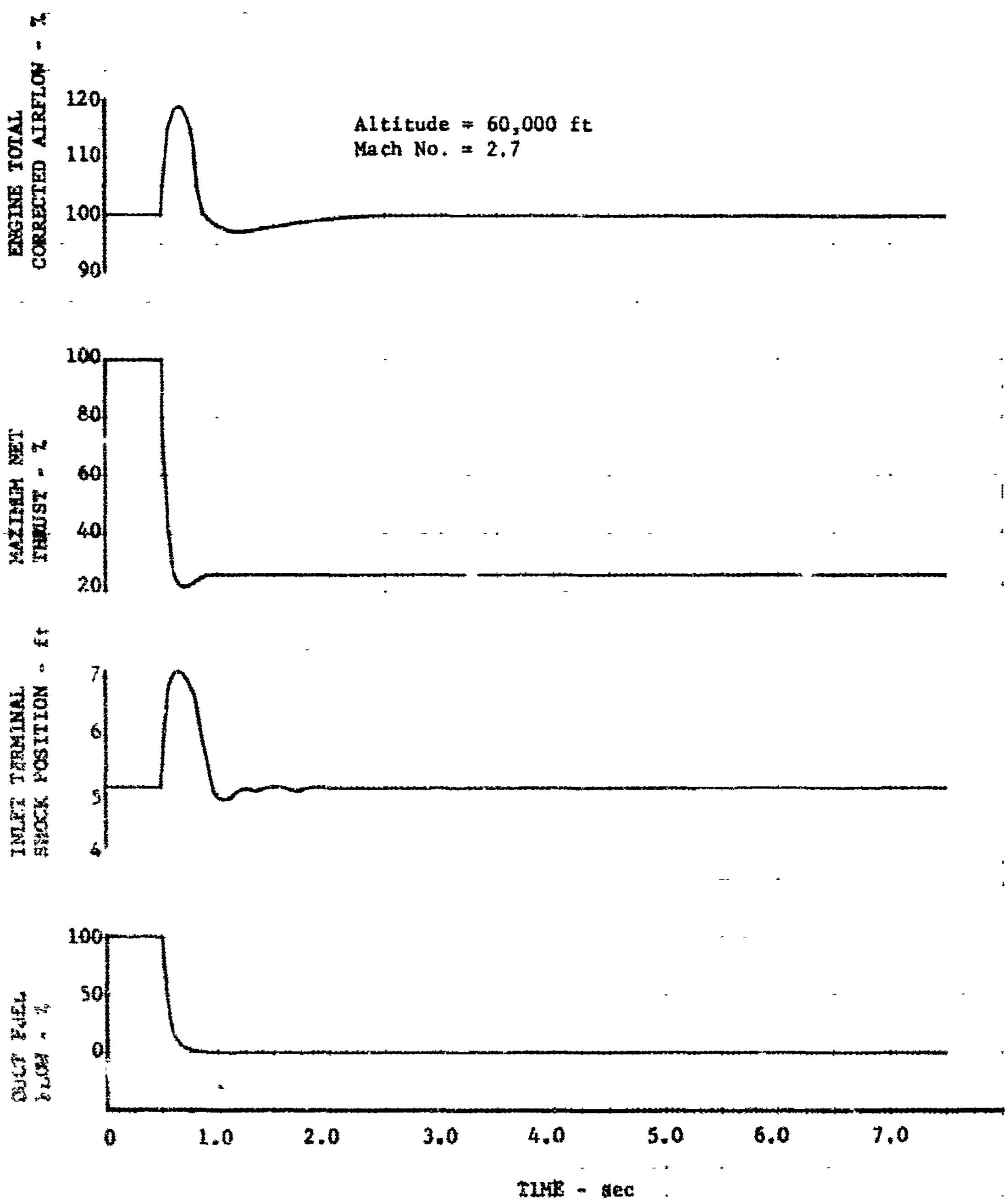


Figure III-K-6. JTF17 Estimated Dynamic Performance, Duct Heater Fuel Cutoff at Climb Thrust

DF 52505

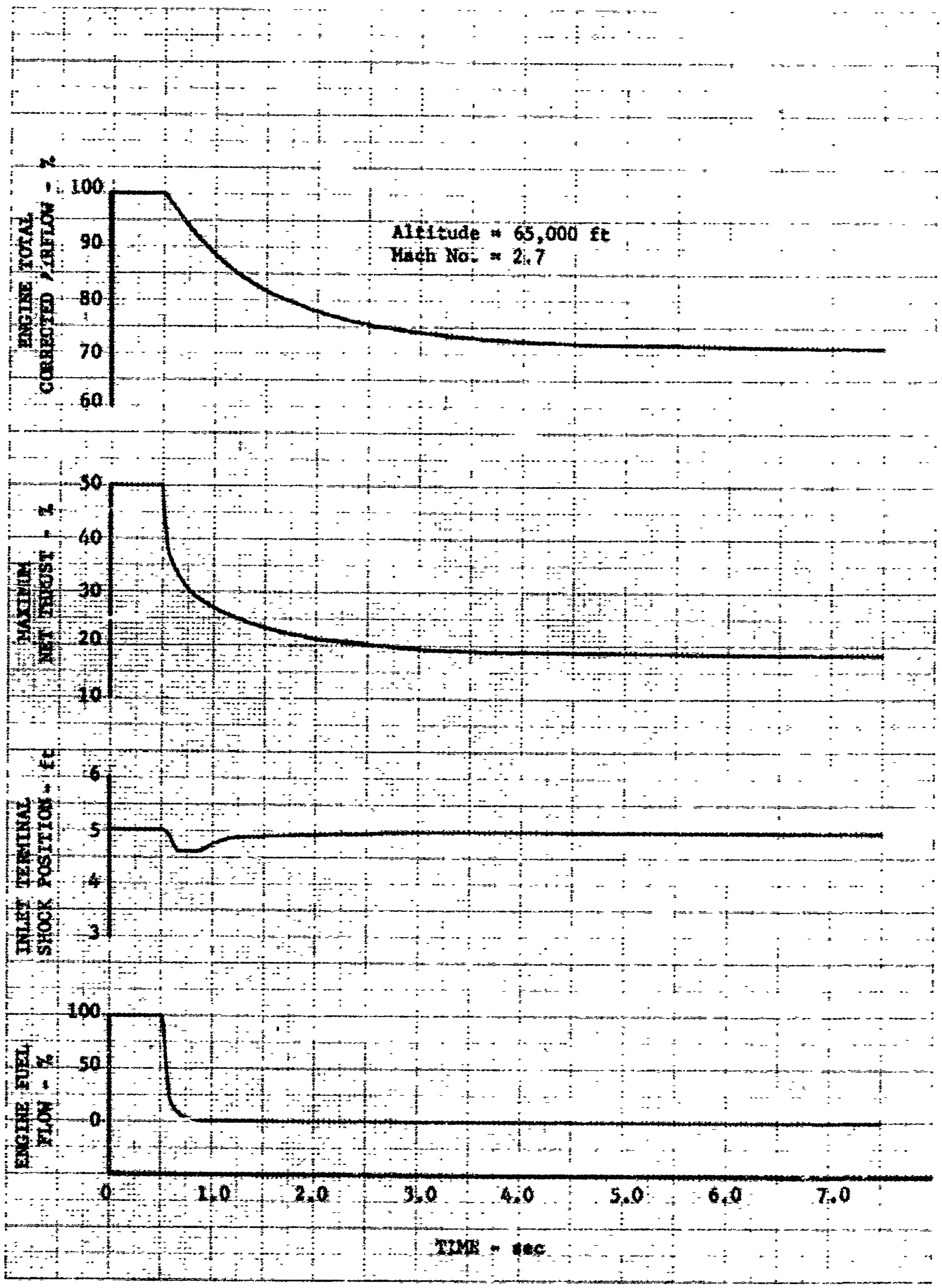


Figure III-K-7. JTF17 Estimated Dynamic Performance, Primary Combustor Fuel Cutoff at Cruise Thrust DF 52506

L. NOISE

The single jet noise model test program discussed in PWA FR-2098 and PWA FR-2156 was completed in the East Hartford anechoic chamber on 22 November 1966. During this test series nine primary nozzle configurations were tested both with and without a blow-in-door ejector. A total of 290 runs were made over a range of jet velocities from 1510 ft/sec to 2270 ft/sec to ensure a complete definition of the nozzle performance of each noise model. Figures III-L-1 and III-L-2 are photographs of several of the mixing nozzles tested. Preliminary results from the initial nozzles tested indicate from 5 to 6 PNdb attenuation from the base case conical nozzle for the 4-lobe-50% penetration-short and for the 4-lobe-50% penetration-long, respectively. See figures III-L-3 and III-L-4. The acoustical performance of the remaining nozzles will be reported next month.

Construction has begun on a resonant liner test section to be run in the East Hartford dual reverberation facility. Delivery of the baseline, nontreated section is scheduled for 1 December, with the treated section delivery scheduled for 8 December. Fabrication and assembly of the associated equipment has begun in East Hartford. This unit was described in the last progress report, PWA FR-2156.

A review of the acoustic performance of eight study engines was initiated. These studies included the evaluation of predicted engine noise level at takeoff, community takeoff, and community approach. None of the engines studied offered any appreciable advantage in noise abatement over the basic JTF17A-21 cycle engine.

Studies were made of recently available data to reevaluate the predicted effect of fan duct resonant liners on rearward propagated fan noise. Data used included absorption coefficient studies measured with an impedance tube at FRDC and Douglas Aircraft, together with results of simulated JTF17 fan duct tests in the dual reverberation chamber at East Hartford. These data substantiate a 15 PNdb attenuation of rearward propagated fan noise as a result of the current diffuser design (see figure III-L-5). Increasing the treated area as shown in figure III-L-6 will provide 24 PNdb attenuation of fan noise.

A study program has been initiated to determine psycho-acoustic reactions to impressed pure tones on a jet noise background as illustrated in figure III-L-7. Previous studies by other investigators suggest that imposed pure tones may be more annoying than the current PNdb scale would indicate. To date, individual reaction to the various levels of pure tone noise indicates that a better method of analysis is required. A suggested approach to improve the validity of the psycho-acoustic study is to evaluate individual reactions through the use of a polygraph which will monitor the subjects reaction to the intensity level of the imposed pure tone. This approach will be evaluated during the initial studies which are scheduled to begin in December.

The rig for determining the reflection of rearward propagated fan noise because of a density gradient in the fan discharge duct has been constructed. (Reference PWA FR-2156.) An analytical evaluation program is being run concurrently with Dr. Ingard as consultant. Testing is scheduled to begin in early December.

The outdoor noise test rig, D-33, is approximately 90% complete. Further delay in the delivery of major parts requires rescheduling of the 1/8-scale JTF17 engine exhaust system to December. The first series of tests on this rig will evaluate the effect of various primary plug configurations run in a coannular exhaust system with blow-in-door ejector to confirm results obtained on the 0.07-scale model run in the East Hartford anechoic chamber in August.

The full-scale, 4-lobe mixing nozzle and blow-in-door ejector (PWA FR-2098) has been constructed and will be tested on a sea level static test stand early in December. This particular configuration of a single jet mixing nozzle has been tested in the anechoic chamber in East Hartford (4-lobe - 50% penetration - long length). Preliminary data from this test indicated attenuation of 6 PNdb.

FE 64561

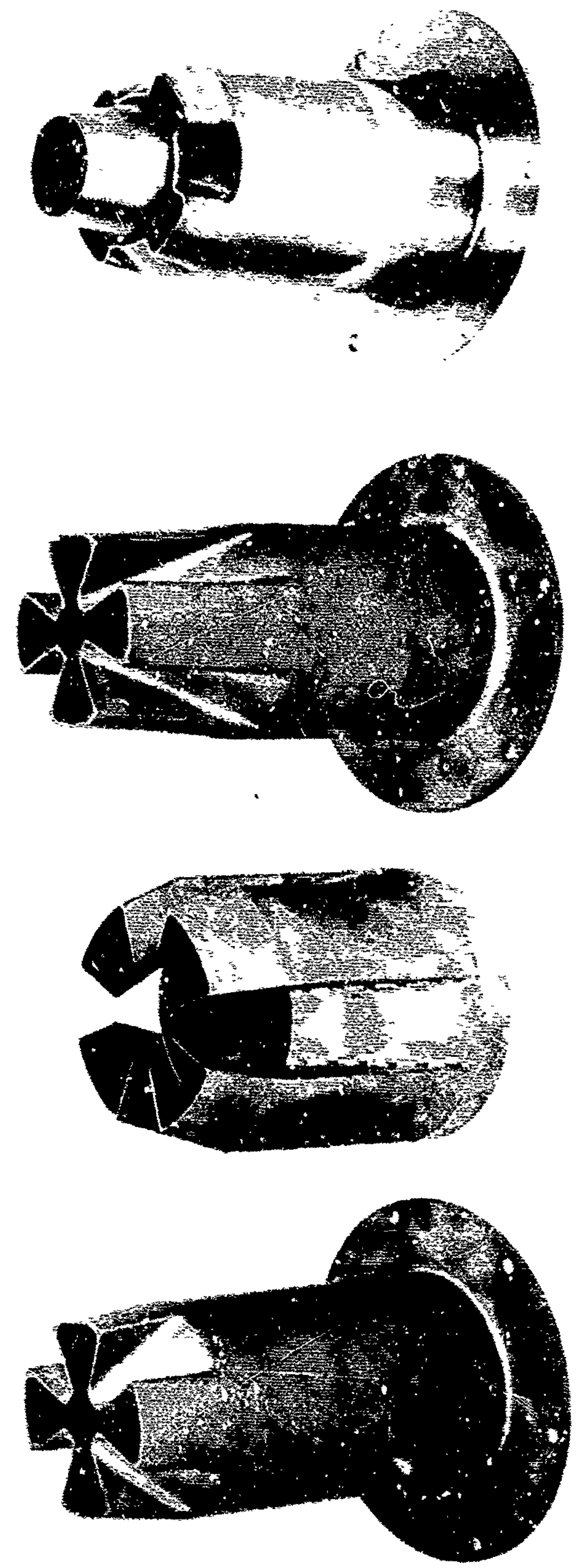


Figure III-L-1. Nozzle Noise Suppressor Models

FE 64560

Figure III-L-2. Nozzle Noise Suppressor Models

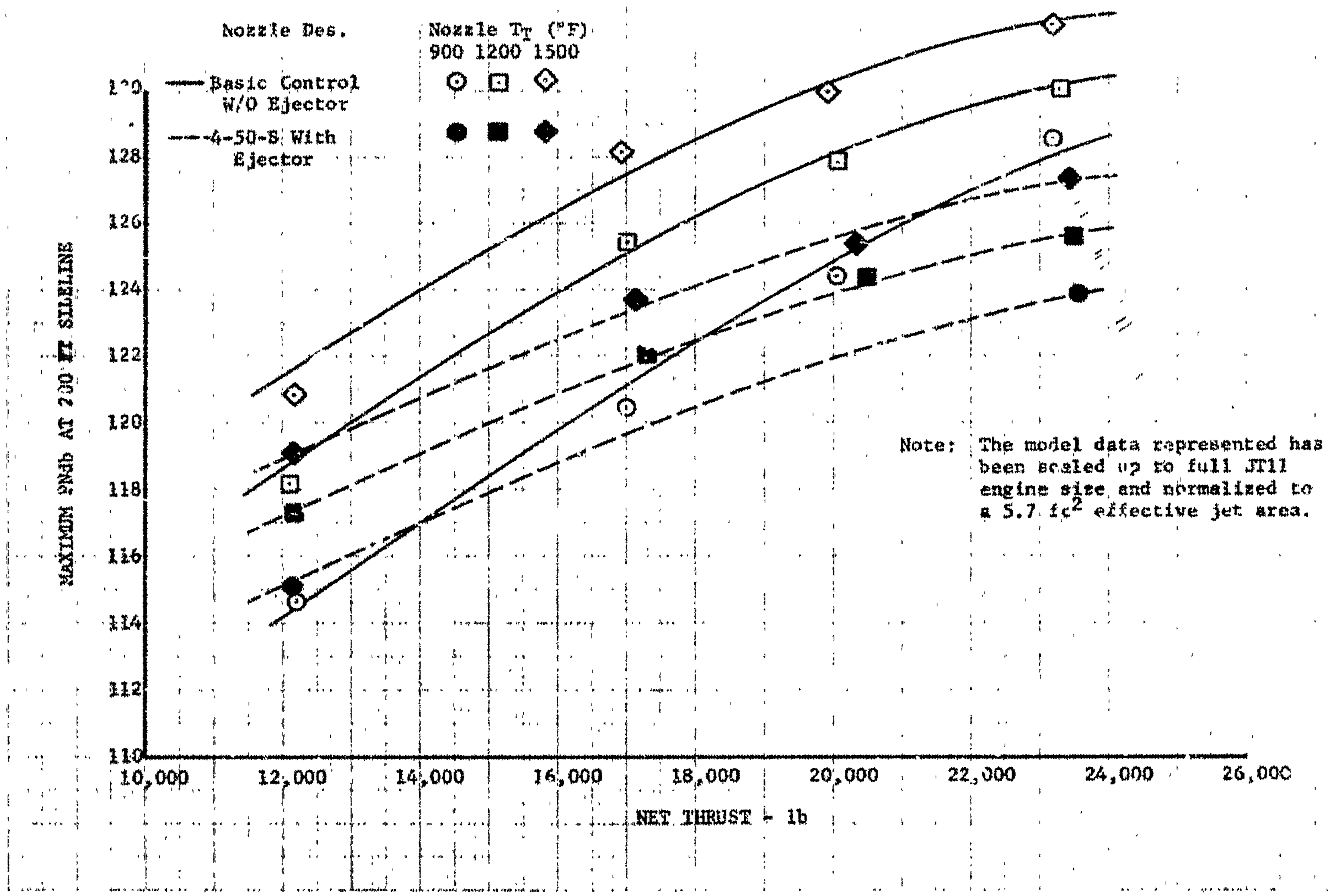


Figure III-L-3. Acoustical Performance of Turbojet Mixing Nozzle Model - 4-Lobe-50% Penetration - Short

DF 52507

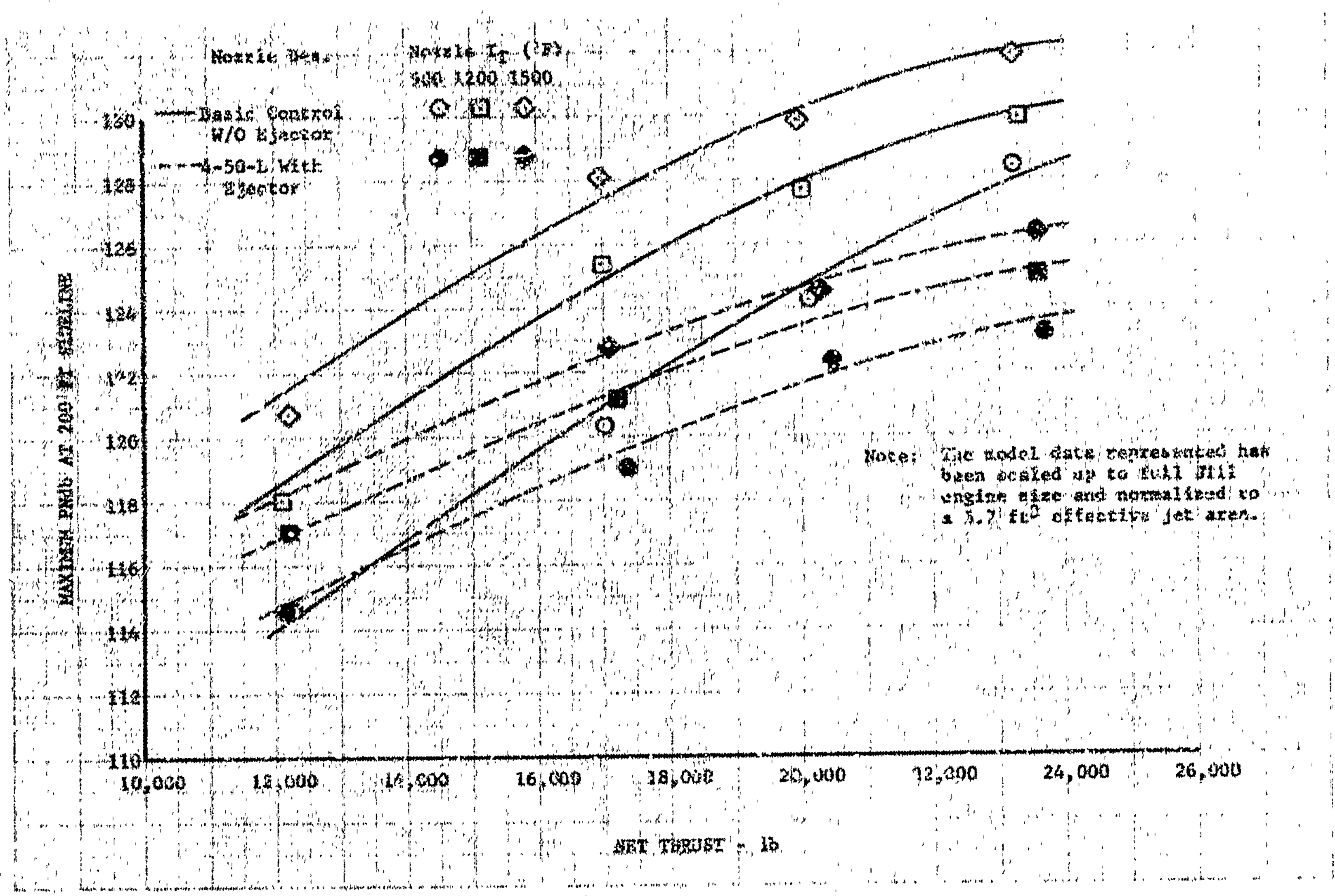


Figure III-L-4. Acoustical Performance of Turbojet Mixing Nozzle Model - 4-Lobe-50% Penetration - Long

DF 52508

Zone A: Flow Splitter and 2 Walls Treated

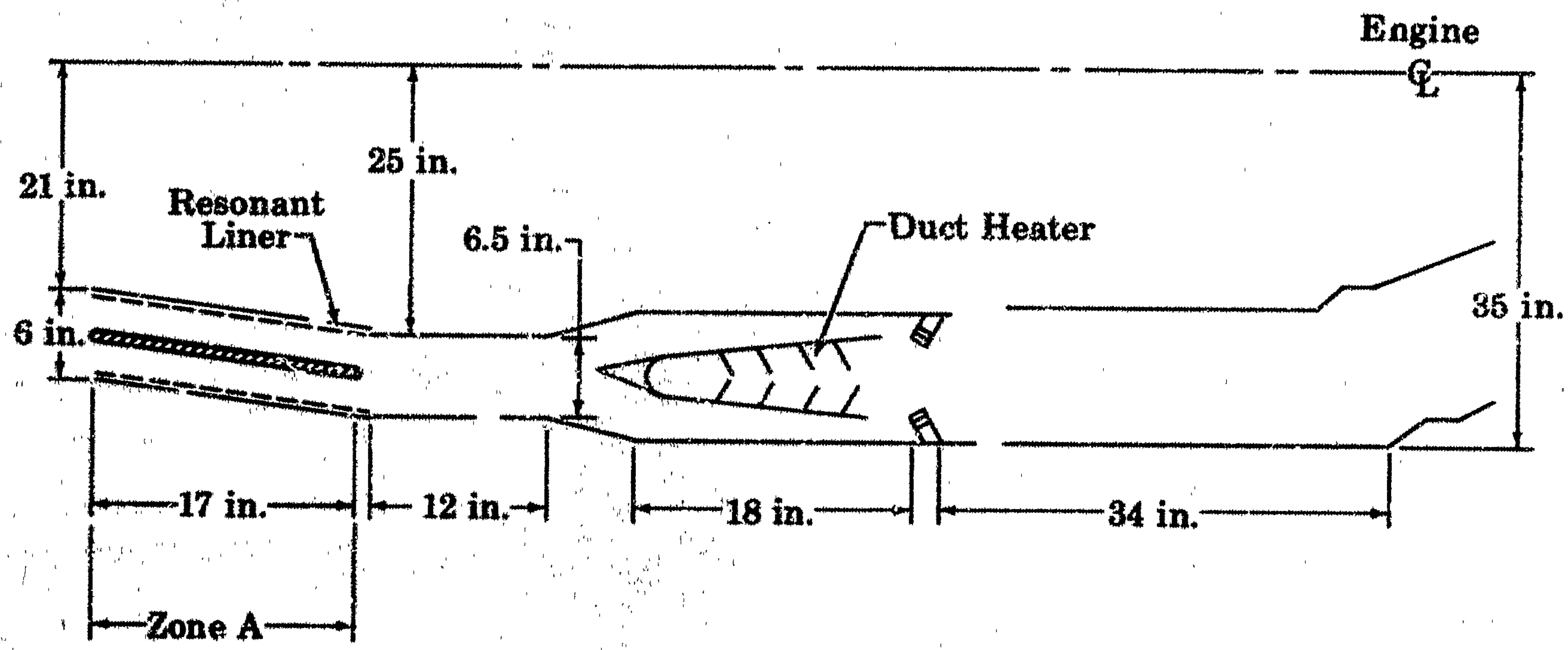
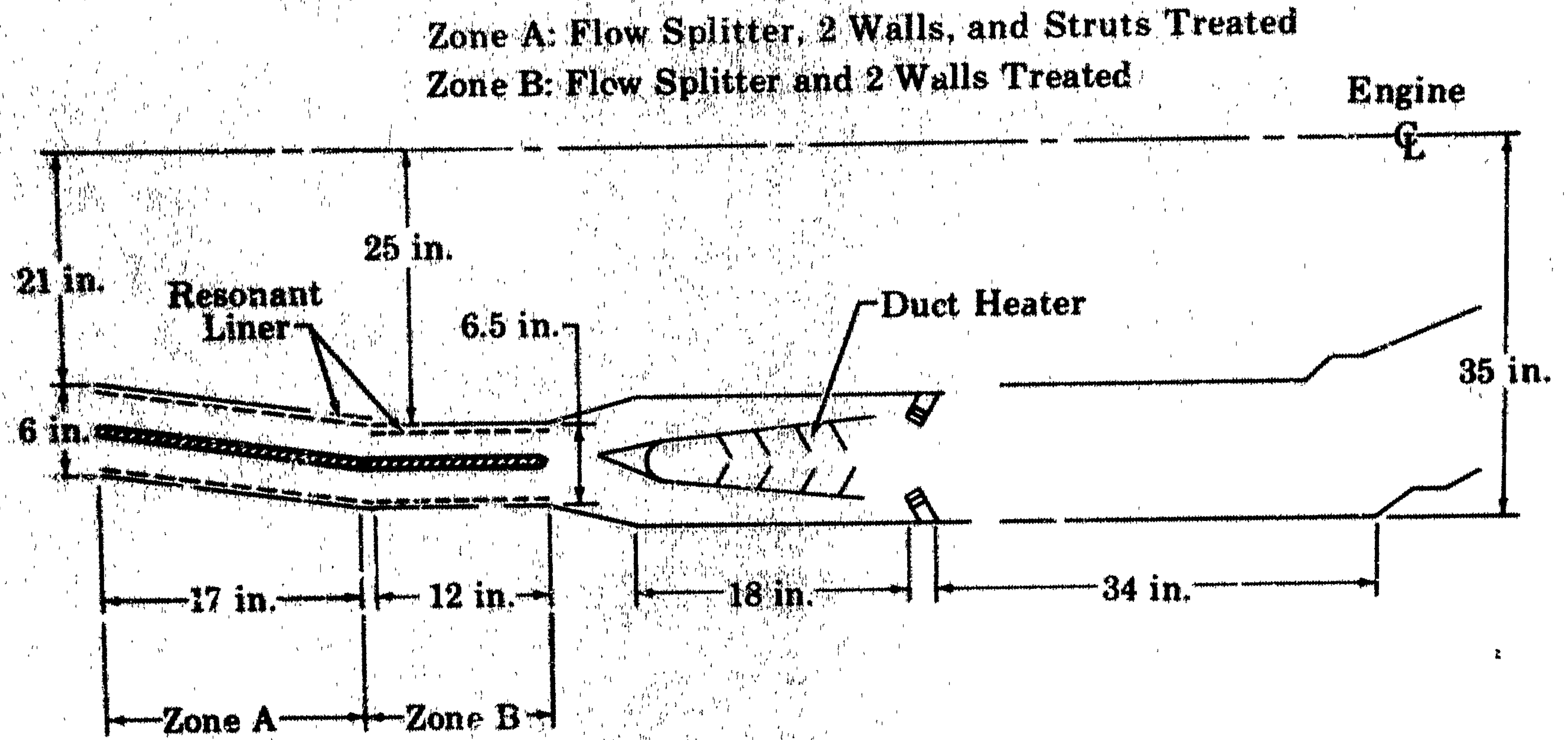


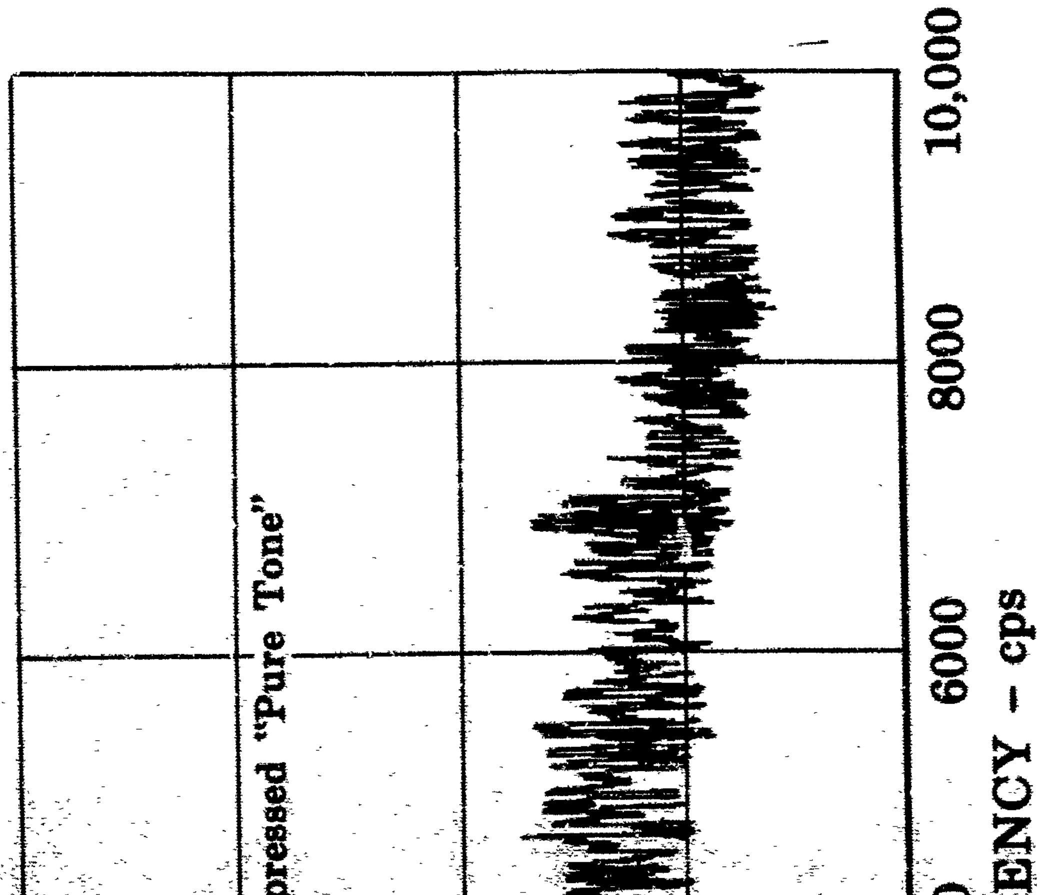
Figure III-L-5. Fan Noise Absorption Liners - Existing Design

FD 19040



FD 19062

Figure III-L-6. Fan Noise Absorption Liners - Growth Version



FD 19063

Figure III-L-7. Spectral Analysis of Jet Noise With "Pure Tone" Impressed

M. MOCKUPS

Revisions to improve the main fuel pump and hydraulic pump configurations for accessibility and maintenance were accomplished on the full-scale engineering mockup.

A scheme for quick disconnect of the accessory gearbox from the unitized fuel control base plate was mocked-up in full scale during this period.

N. COORDINATION

1. General

Messrs. H. T. Luskin, Assistant General Manager, SST Propulsion and J. Stroud and E. Bragden, Propulsion Group, LCC, visited FRDC on 4 November, for briefing on JTF17 hardware development progress since 6 September Phase III Proposal submittal.

The following Source Selection Council members visited FRDC on 10 November for SST discussions:

Mr. D. D. Thomas, Associate Administrator, FAA

Mr. A. Dean, Associate Administrator for Administration, FAA

Mr. J. Blatt, Associate Administrator for Development, FAA

Mr. O. Bakke, Eastern Regional Director, FAA

Mr. N. Goodrich, General Counsel, FAA

Mr. J. H. Hoover, Special Assistant to Associate Administrator, FAA

Mr. E. W. Stimpson, Assistant Administrator, Office of Congressional Liaison, FAA

Dr. R. Bisplinghoff

The FAA SST Supplementary Engine Evaluation Task Force visited FRDC on 16 and 17 November to review the SST engine and rig test results since the SST evaluation team visit during the week of 19 September.

Mr. F. A. Maxam, Chief Engineer, SST Program, The Boeing Company, visited FRDC on 16 November for SST discussions with Mr. W. L. Gorton, FRDC General Manager. Other Boeing SST visitors during this report period included: Messrs. R. S. Neuhart, Chief, Power Plant Design, and J. J. Hamry, Power Plant Design, on 4 November and Messrs. K. Chun, D. Swanson, and D. Smith, SST Propulsion Staff Group, on 7 and 8 November.

Dr. N. Golovan, Office of Science and Technology, visited FRDC on 18 November for JTF17 SST engine discussions.

Messrs. W. L. Gorton, FRDC General Manager, B. N. Torell, Chief Engineer, W. H. Brown, Assistant Chief Engineer, and H. N. Cotter and P. L. Bosse, Performance Engineering Group, visited Lockheed on 21 November and The Boeing Company on 22 November for engine and airplane growth discussion.

FRDC performance engineers visited LCC on 14 November and Boeing on 15 November for thrust measurement system discussions.

JTF17A-21 noise abatement study decks were transmitted to both Lockheed and Boeing. Both IBM 7090 and IBM 360 system decks were provided.

Data on the JTF17 engine combustor relight characteristics were sent to both Lockheed and Boeing.

2. JTF17A-21L Engine

A P&WA-Lockheed installation coordination meeting was held at FRDC on 27 and 28 October. The meeting covered general review of both airplane and engine programs and open items on installation design.

As requested by Lockheed, an IBM 360 study performance deck, comparable in performance to the specification IBM 7090 deck, was provided to aid Lockheed in setting up their IBM 360 system.

Studies are in progress concerning relocation of front mount pads, a revised rear mount lug configuration, and possible engine movement with respect to airframe in the event of a failed front or rear mount system.

Studies are continuing on control drive motor locations and reverser/fuel control interlock configurations. A Lockheed drive motor specification has been requested to aid these studies.

In response to Lockheed's request, a reverser-suppressor outer skin temperature profile, from the nacelle/reverser-suppressor mating face to the tail feather exit plane,was generated and transmitted to them.

Lockheed was provided with data and drawings to initiate coordination on the design of their 0.6-scale diffuser to the run with the 0.6-scale fan rig at the Willgoos Laboratory in July 1967.

3. JTF17A-21B Engine

FRDC performance and installation engineering personnel visited Boeing on 7, 8, and 9 November for discussions on performance, mission analysis, economics, engine and airplane growth, and engine cycles.

Boeing SST staff performance personnel visited FRDC on 7 and 8 November to deliver and review the Boeing dynamic inlet simulation. The study will be used to investigate engine/inlet compatibility in the flight Mach number range of 2.2 to 2.7. Boeing and FRDC will periodically meet to coordinate study results.

During the Boeing visit of 4 November, progress was made in improving areas of installation compatibility relative to engine mount system, nacelle/reverser-suppressor mate-up, inlet/engine mate-up, power takeoff gearbox, power lever and fuel shutoff lever attachments, air bleed and power extraction requirements, windmill brake actuation requirements, fuel tank drain installation, ground handling, and engine operating envelope. The schedule for updating the Boeing JTF17A-21B mockup engine was reviewed.

An FRDC acoustic engineer visited Boeing on 21 November to review P&WA fan rig noise test data and noise calculation methods.

Data on the JTF17 reverser-suppressor were transmitted to Boeing in support of their reverser-suppressor design study for the SST.

O. MAINTAINABILITY

The split primary burner case configuration has been redesigned to an annular case ... is translated to gain access to the primary burner modules. The elimination of the split case reduces the number of bolts required, thus reducing maintenance man hours. Also the problem of alignment of distorted case halves at reassembly has been eliminated. The translating of the annular burner case can be readily accomplished as presently done on the P&WA JT3D engine.

The access panels to the gas generator have been redesigned to reduce the number of bolts required for disassembly by approximately 20%. The previous design required a large number of bolts in each panel since the panels were structural members of the outer engine cases. Present access panels are nonstructural members and therefore require a minimum amount of fasteners to attach to the engine. This reduces the elapsed time maintenance man hours required to gain access to the gas generator fuel nozzles, fuel manifolds, and start bleed valves.

A mockup of the access panel area will be built to permit demonstration of maximum accessibility of the gas generator area through the panel openings, and to determine the size and strategic location of the panels.

Further studies of the Customer Maintenance or Overhaul Errors, documented by our Service Records department for the period of January 1961 to April 1966 have been made. Analysis of the data has assisted the Design Maintainability group in preventing error-inducing designs from being incorporated into the JTF17 engine.

The following design layouts and studies are in process which will improve the maintainability characteristics of the JTF17 engine.

1. A study and redesign for the attachment of the fan stator assembly versus the location of the controls. The ultimate objective is to have the bolts that attach the fan stator assembly accessible without having to remove any controls.

2. Incorporate provisions whereby individual compartment breather flow checks may be made.

3. A design for a simplified attachment between the variable inlet guide vane and the connecting lever.

4. A study as to the possibility of incorporating borescope provisions for inspection of compressor disk rims and webs outside of compressor disk spacers.

Maintainability presentations were made at the ATA conference in Los Angeles, California by Service and Design personnel. Brochures entitled "Maintainability and Reliability Trends for the New Generation of Aircraft Engines" were distributed at this meeting.

A visit was made to American Airlines in Tulsa, Oklahoma, by Service Department personnel to present films of maintainability and to provide verbal description of JTF17 engine configuration and maintainability features.

Documentation of procedures for the repair of turbine exhaust case vanes has been prepared.

P. VALUE ENGINEERING

Value Engineering proposals completed during the month of November include:

1. Value Engineering proposal No. 3.18 revises the anti-vortex tubes. Potential savings of $198 per engine
2. Value Engineering proposal No. 4.07 proposes a change in the material of the duct heater case support from a forging to a casting. Potential savings of $1308 per engine
3. Value Engineering proposal No. 3.20 proposes a change in the material of the 6th, 7th, and exit compressor stage shrouds from INCO 718 to INCONEL. Potential savings of $45 per engine.

Value Engineering cost studies completed during this report period include:

1. Forged versus cast fuel nozzle supports
2. Rear mount case as a weldment vs single forging
3. Estimated cost of titanium honeycomb noise suppression liners in the fan exit duct and duct diffuser
4. Cost of cast module tracks for primary and duct burner
5. Aerobrake
6. Anti-vortex tube
7. "Z" spacer in high compressor
8. Integral versus welded borescope pad on rear mount case
9. Proposed material change to Waspaloy on inner and outer transition duct cases.

During this month, Value Engineering also:

1. Revised the contour of the primary combustor case and the diffuser case to straight conical sections, which permits a gear shaping process instead of contour milling

2. Investigated possibility of casting link arm on Aerobrake in place of machined forging

3. Continued liaison with East Hartford Production Engineering to ensure that the engine design is adaptable to production techniques.

Q. CONFIGURATION MANAGEMENT

Design of the prototype engine is continuing with incorporation of coordinated interfaces. Detail changes required on some interface items are being coordinated with the airframe manufacturers as design of the engine and airframe progresses. All proposed changes are being transmitted by Field Survey layouts with a log of dates of transmittal and acceptance or rejection by the airframe manufacturer. The basic configuration of the engine is unaffected by these changes.

On 4 November Boeing propulsion system engineers visited FRDC for installation coordination. The major topics of discussion included inlet/engine mate-up, reverser-suppressor mate-up, windmill brake requirements, drain system, and horsepower extraction. Problems in each category were discussed, and the required action by both parties was determined. Boeing provided a revised presentation of horsepower extraction which is being reviewed.

R. QUALITY ASSURANCE

Experimentation with the Defectometer, an eddy current defect detector, manufactured by Automation Foerster, has demonstrated the capability of indicating tightly closed cracks 0.010 inch deep by 0.060 inch long in cast turbine blades. Work with this equipment is continuing, and purchase of the equipment for use during Phase III is under consideration.

Work with turbine blade airfoil wall thickness measurement techniques and equipment has greatly increased confidence in the ability of the inspection procedures now in use to control turbine blade airfoil thickness in critical areas. Points of measurement for the 2nd-stage blades are shown in figure III-R-1.

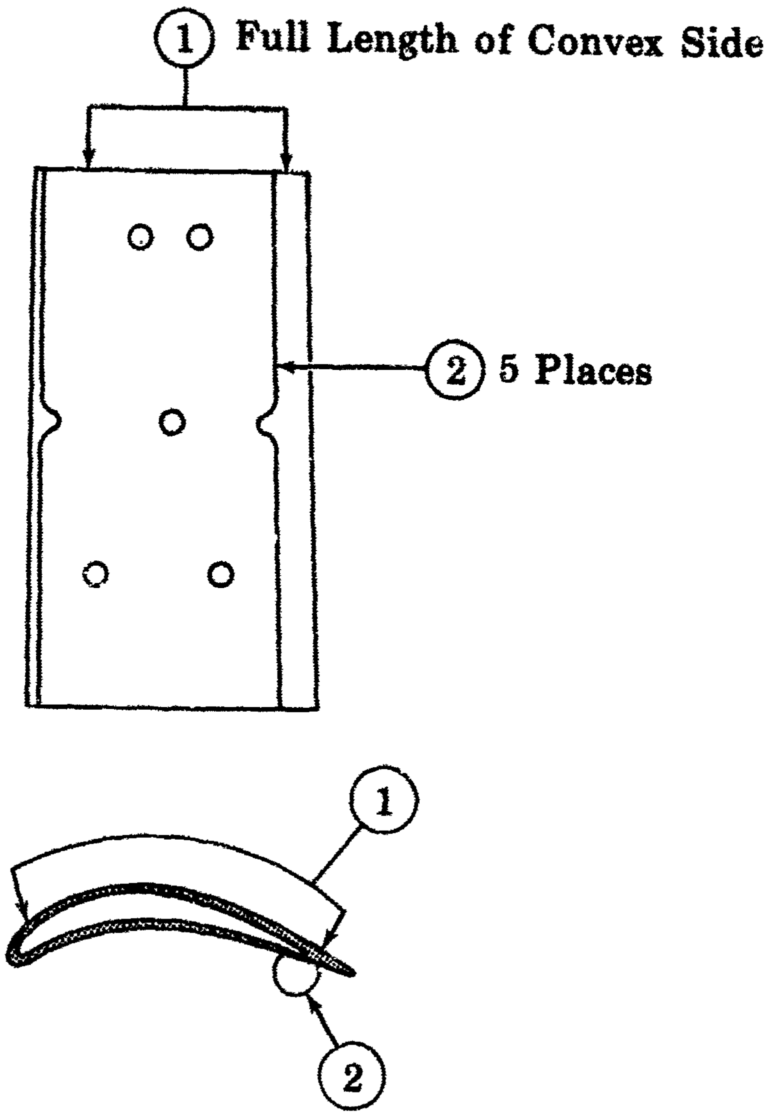


Figure III-R-1. JTF17 2nd-Stage Turbine Blade Wall Thickness Measurements

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S. RELIABILITY

1. Design Reviews

Approximately 24 prototype engine layouts are in process of review.

2. Failure Mode and Effect Analysis

The rough draft of the third edition of the Failure Mode and Effect Analysis is now being reviewed by Design and Project Engineering.

3. Special Reliability Studies

A computerized data retrieval program has been devised to permit rapid compilation and presentation of statistical information pertaining to commercial engine inflight shutdowns and premature engine removals. Coding of all entries and preliminary tabulations have been completed.

A study of all P&WA turbine engine disk failures resulting in engine case penetrations on commercial aircraft since the beginning of service has been completed.

The pertinent results of this study were as follows:

1. Fifteen disk failures in 34,000,000 engine operating hours.
2. Of those failures which were primary disk failures, two resulted in fuselage penetration.
3. One instance of a disk failure resulted in fuselage penetration at altitude. This was a secondary disk failure.
4. The JTF17 engine design incorporates features to preclude the primary failures found in this study that can escalate into disk failures.
5. The engine design also incorporates configurations to reduce the possibility of primary disk failures from fatigue, such as the elimination of bolt holes in the disk portion of the titanium fan rotors, elliptical broach slots, integral spacers and disks, and long snap diameters for the high compressor rotors.

A study of the JT8D No. 4 breather tube failures has been completed and all pertinent information transmitted to the engineers designing the JTF17 breather system.

A study is in progress to determine the feasibility of retaining the inner platform of the 1st-stage turbine vanes to prevent failure escalation in the event that both airfoils of a paired vane have been severed.

A study of the JT8D 6th-stage compressor blade root problem is in progress to ensure that a similar condition will not exist on the JTF17 engine.

4. Parts History Survey

The parts history data retrieval system was utilized to determine the test exposure time of the 3rd-stage compressor air seal on the high compressor component test stand.

5. Reliability Training

Three reliability training films listed below were obtained from the U.S. Air Force and viewed by the Design and Development Reliability Groups.

1. "No Second Chance"
2. "Maintainability - Design/Living"
3. "AGREE in Action."

6. Statistical Engineering

To determine jet fuel storage requirements, an analytical study is being made of the jet test fuel demands and fuel storage supply capabilities. The study has produced a curve showing the probability distribution of fuel consumption for each test area.

SECTION IV
AIRLINE COMMENTS

Preliminary test stand requirements for the JTF17 engine have been established and transmitted, in answer to specific requests, to Pan American World Airways, American Airlines, United Airlines, and Trans-World Airlines for use in planning their engine test stands. These requirements are also being made available to all the other domestic and world-wide airlines who have expressed an interest.

SECTION V
STATE-OF-THE-ART

Development testing of main shaft seals for advanced air-breathing propulsion systems under Contract NAS3-7609 is continuing with completion scheduled for June 1967. This program was discussed in Section V of the July Progress Report PWA FR-1953. Progress to date follows:

1. A total of 70 hours of calibration time has been accumulated on rubbing face seals. Testing is continuing in order to establish the operational limits of this type seal configuration.

2. Approximately 18 hours have been accumulated on the orifice compensated concept. Difficulty has been encountered in achieving leakage rates comparable to those of rubbing face seals. Testing is continuing.

   More specific information may be obtained from Progress Reports PWA-2879 and 2958.

A similar Contract (NAS3-7605) that covers development of compressor end seals, stator interstage seals, and stator pivot seals has been initiated. The object is to provide development data for the design of the above type seals for advanced air-breathing propulsion systems. The program will entail concept feasibility studies leading to the design and testing of hardware. The ultimate goal is to achieve increased compressor efficiency through the use of seals that have much lower air leakage rates than seals currently in use while retaining or improving the reliability and weight factors.

Preliminary designs have been completed and submitted to NASA for approval.